XVI INTERNATIONAL GEOLOGICAL CONGRESS

GUIDEBOOK 2 - - - EXCURSION A-2

# MINING DISTRICTS OF THE EASTERN STATES

International Geological Congress
XVI session
United States, 1933

Guidebook 2: Excursion A–2

# MINING DISTRICTS OF THE EASTERN STATES

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UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1932

For sale by the Superintendent of Documents, Washington, D. C. - - - - - - Price 20 cents

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# MINING DISTRICTS OF THE EASTERN STATES

## INTRODUCTION

By Joseph T. Singewald, Jr.

### ITINERARY

Excursion A–2 (see fig. 1) is planned for economic geologists and includes most of the important metal-mining districts and some of the nonmetallic and coal districts of the southeastern United States and the Mississippi Valley. The duration of the excursion will be 11 days and 12 nights. Because of the large area traversed the excursion will necessitate 3,500 miles (over 5,600 kilometers) of railroad travel. In order to utilize the time to the best advantage, travel between the districts will be at night and the days will be devoted to the geologic visits.

A wide range of mineral deposits are included in the itinerary, embracing metals, nonmetals, and coal. Half a day will be spent at the classic petrographic locality of Magnet Cove, Arkansas; otherwise the time of the excursion will be devoted entirely to economic geology. The districts that will be visited and the principal features of interest that will be shown are listed below.

Pittsburgh district, Pennsylvania: The Pittsburgh coal seam is the most valuable single coal seam in the United States and underlies a large area in western Pennsylvania, West Virginia, Ohio, and Kentucky. Pittsburgh is also the greatest iron and steel manufacturing center in the United States. Visits will be made to the Warden coal mine of the Pittsburgh Coal Co., on the Pittsburgh seam, and its coal-washing plant, and to the Aliquippa works of the Jones & Laughlin Steel Co.

Bedford, Indiana: The Bedford oolitic limestone district has the largest production of building stone in the country.

Rosiclare, Illinois: The veins and replacement deposits of the Illinois-Kentucky fluorspar district produce more than 95 per cent of the fluorspar mined in the United States.

Southeastern Missouri lead district: This district, containing disseminated lead ore in dolomite, is the most productive lead district in the United States, producing nearly one-third of the total lead output of the country.

Pilot Knob and Iron Mountain, Missouri: The specular hematite deposits of these districts, though not large producers, are of much geologic interest.

Tri-State zinc-lead district, Missouri, Kansas, and Oklahoma: Here lead and zinc ores occur in limestone and chert breccias. The district produces more than two-fifths of the zinc output of the United States and is the largest producing district in the country.

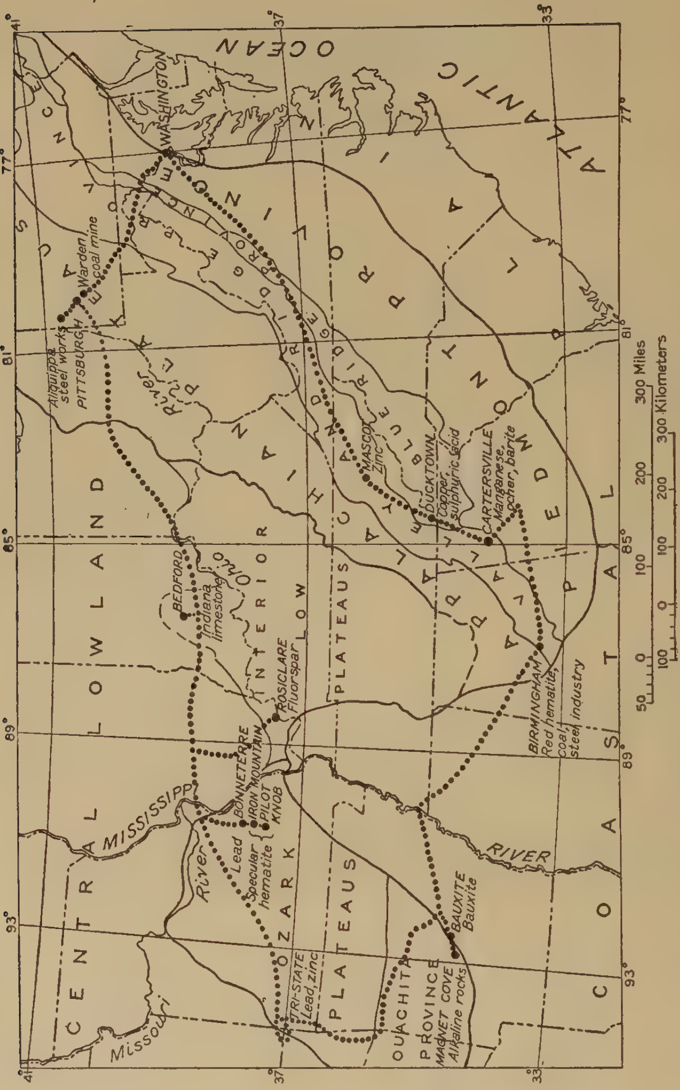


FIGURE 1.—Map showing route of excursion A-2

Bauxite in Arkansas: These bauxite deposits are associated with syenite and produce more than 95 per cent of the bauxite output of the United States.

Magnet Cove, Arkansas: This is a well-known petrographic province characterized by a great variety of unusual alkaline rocks.

Birmingham, Alabama: The Clinton red hematite deposits make the Birmingham district the second largest producer of iron ore in the United States, and the coke from the adjoining Warrior coal field has allowed the district to develop into one of the principal iron and steel manufacturing centers. Both the iron ore and the coal deposits will be visited.

Cartersville, Georgia: The manganese, barite, and other deposits of this region are no longer of great economic importance, but they illustrate the residual types of mineral deposits that occur widely over the Southern States.

Ducktown, Tennessee: The cupriferous iron sulphides of Ducktown make it the largest producer of copper in the Eastern States, though its production is exceeded by that of the large western districts. The ores are smelted in the district. The district is also one of the principal producers of by-product sulphuric acid.

Mascot and Jefferson City, Tennessee: The zinc ores occur in a brecciated zone in dolomite. These large zinc mines have recently been developed in a lead and zinc area extending from northeastern Tennessee to southwestern Virginia.

The itinerary of the excursion includes, therefore, mining districts of the first magnitude. In addition to affording a study of a wide variety of mineral deposits, with reference both to the products and to their geologic and genetic relations, the excursion illustrates modern large-scale mining and metallurgical practices in the United States.

## GEOLOGIC SETTING

The excursion traverses in order from east to west the following geomorphic provinces: The Piedmont province, the Blue Ridge province, the Valley and Ridge province, the Appalachian Plateaus, the Mississippi Valley, the Ozark uplift, the Ouachita province, and the upper part of the Mississippi embayment. (See fig. 1.)

The Piedmont is underlain by the ancient crystalline complex. It consists chiefly of plutonic igneous rocks, gneisses, and schists. None of its mineral deposits are included in this excursion.

The Blue Ridge province is made up of highly folded and metamorphosed pre-Cambrian and earliest Cambrian rocks. The Ducktown district lies near the southern extremity of this province, in the Cambrian Great Smoky formation.

Birmingham, Cartersville, and Mascot lie in the Valley and Ridge province, which is underlain by lower Paleozoic formations that are highly folded and overthrust to the northwest. The Cartersville mineral deposits are in and overlie the Cambrian Weisner quartzite and Shady limestone. The Mascot zinc ores are in the Upper Cambrian portion of the Knox dolomite. The Clinton iron ores of the Birmingham district are in the Rockwood formation, of Silurian age.

The Appalachian Plateaus are underlain by relatively flat-lying or gently folded upper Paleozoic formations. The intensity of folding decreases westward. The Pittsburgh coal seams and the Warrior coal field of Alabama lie in this province. The coals of both districts are of Pennsylvanian age.

The Mississippi Valley region consists of generally flat-lying, little disturbed Paleozoic formations. Only locally are there strong faults or pronounced folds. The Bedford building stone, the Rosiclare fluorspar, and the Missouri lead districts lie in this province. The Missouri lead ores occur in the Upper Cambrian Bonneterre dolomite and to a minor extent in the underlying Lamotte sandstone. The Bedford oolitic limestone (also known as Indiana limestone) was deposited in the Meramec epoch of the lower Mississippian. The country rock of the Illinois-Kentucky fluorspar region extends from the lower Mississippian (Meramec) formations to those of the upper Mississippian (middle Chester). The strata are principally limestone but include also shale and sandstone.

The Ozark uplift is a domal uplift in the central portion of which are gently dipping lower Paleozoic formations and around the flanks still flatter upper Paleozoic formations. The Cambrian formations of the lead district are at the eastern edge of the uplift. The tri-State zinc and lead district is just beyond the southwestern margin. The ores of the zinc district occur in the limestones and cherts of the lower Mississippian Boone formation. On the east side of the uplift pre-Cambrian granites and porphyries constitute a group of hills called the St. Francois Mountains, which project through the Cambrian formations. The Iron Mountain and Pilot Knob hematite deposits occur in these porphyries.

Magnet Cove and Bauxite, Arkansas, are close to the southeastern border of the Ouachita Mountains. Magnet Cove is just inside of the Ouachita province and Bauxite just outside, in the Mississippi embayment of the Coastal Plain. Magnet Cove is a differentiated complex of alkaline nepheline syenite of probable Cretaceous age, which intrudes the intricately folded Paleozoic rocks of the Ouachita Mountains. The bauxite deposits are likewise associated with Cretaceous nepheline syenites intruded into the Paleozoic basement but now cropping out in the Tertiary deposits of the Mississippi embayment that were laid down upon them.

## TYPES OF DEPOSITS

The mineral deposits visited by the excursion range in genetic character from those formed by magmatic segregation to those resulting from the weathering of preexistent materials and their

residual, alluvial, and colluvial accumulation. The deposits whose mode of origin was nearest akin to magmatic segregation are the hematite iron ores of Iron Mountain and Pilot Knob. Pyrometasomatic deposits are represented by Ducktown, Tennessee, where the masses of cupriferous pyrite are regarded as the result of high-temperature replacement of limestone lenses in the Great Smoky formation.

The tri-State zinc and lead district, the Missouri lead district, the Illinois-Kentucky fluorspar district, and the Mascot zinc district are typical representatives of a class of ore deposits, widespread in the Mississippi Valley and the eastern United States, concerning the origin of which widely divergent views are held. They all occur in Paleozoic limestones and dolomites. The localization of the ores has been guided by fracturing and brecciation, but replacement has been extensive. Only low-temperature ore and gangue minerals have been deposited. Exposures of igneous rocks are unknown in the tri-State and Mascot districts and are small and few in the Missouri lead district and the fluorspar district. One group of geologists has regarded these deposits as formed by circulating meteoric waters, either deep artesian waters or even directly descending supergene waters. Another group has equally vigorously contended for a hydrothermal origin from magmatic solutions.

The genetic relations of the deposits of the Cartersville district are somewhat obscure. The ocher may be the product of hydrothermal solutions. The barite deposits represent residual accumulations. The manganese deposits had generally been regarded as residual, but they are in part at least alluvial and colluvial. The Arkansas bauxite deposits are the residual products of rock decay and weathering.

The Alabama iron ores are of sedimentary origin. The Bedford limestone and the Pittsburgh and Warrior coal deposits are, of course, sedimentary deposits.

## TIME OF MINERALIZATION

Except for the sedimentary deposits, the time of ore deposition has not been very definitely determined. The geologic record since Paleozoic time is very incomplete in the region covered by the excursion, so that it is difficult to fix closely and with certainty the periods of mineralization. In the lead, zinc, and fluorspar districts the problem is tied up with the divergent views concerning the origin of the ores. Furthermore, the proponents of hydrothermal origin are not in agreement about the age of the genetically related igneous rocks, whether they are late Paleozoic or Cretaceous. In the Ducktown district

similar difficulties are met. The mineralization in all these districts may have taken place as early as late Paleozoic time or it may have occurred some time during the Mezozoic.

The Missouri hematites are of pre-Cambrian age.

The Arkansas bauxites were formed prior to the deposition of the Tertiary beds that now in part cover them. The secondary deposits of the Cartersville district seem to be related chronologically to an erosion cycle earlier than the Recent.

# THE PITTSBURGH DISTRICT PENNSYLVANIA [1]

By M. W. von Bernewitz

ABSTRACT

The Pittsburgh district is the greatest iron and steel center of the United States and lies in the heart of the bituminous coal fields of Pennsylvania. The industrial and mining region centered about and tributary to Pittsburgh includes the entire southwest corner of the State, an area more than 50 miles (80 kilometers) from east to west and nearly 75 miles (120 kilometers) from north to south. The district owes its development to the presence of the great Pittsburgh coal seam.

The rocks of the district are of Carboniferous age, and most of the surface is underlain by Pennsylvanian strata. The district occupies a very gentle syncline with southwestward-pitching axis. Dips are measured in feet per mile. The Pittsburgh, Redstone, and Freeport coals have been the most productive. Other seams constitute important reserves for the future. The total recoverable coal is estimated at 19,000,000,000 tons (17,230,000,000 metric tons).

The Pittsburgh seam averages 7 feet (2.1 meters) in thickness. It ranges from 32 to 40 per cent volatile matter, 6 to 10 per cent ash, and from under 1 to over 3 per cent sulphur. The highest-grade coking and gas coals occur in the eastern part of the district.

Other important mineral resources of the district are oil and gas; shale and clay that support a large brick industry; limestones used as flux, as commercial stone, and for lime burning; and sand and gravel.

The Warden coal mine of the Pittsburgh Coal Co. and the Warden coal-washing plant are illustrative of modern coal-mining methods and preparation in the Pittsburgh seam. The Aliquippa works of the Jones & Laughlin Steel Corporation illustrate a large, self-contained steel company with its diversified operations.

## INTRODUCTION

The Pittsburgh district is one of the great industrial centers of the United States, lying in the heart of the bituminous coal fields of Pennsylvania. (See fig. 2.) The early settlement, known as Fort Pitt, dates from 1749, and its growth was rapid because of its location at the confluence of the Monongahela and Allegheny Rivers, which here combine to form the Ohio River, and the accessibility of valuable deposits of coal, oil, gas, clay, limestone, and other natural resources. The Monongahela and Allegheny Rivers are both navigable by steamer and barge, and the Ohio,

[1] These notes were written early in 1931, and the data given apply to that date.

during most of the year, is navigable to the Mississippi. In 1930 the population of the city of Pittsburgh was reported as

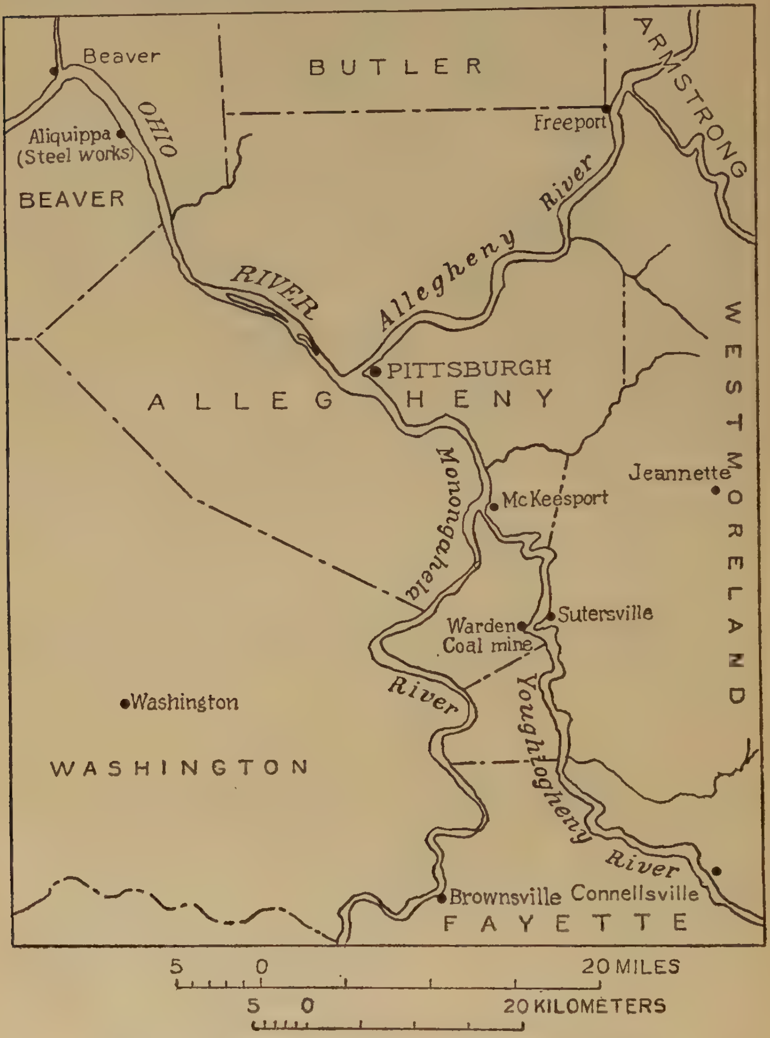


FIGURE 2.—Index map of Pittsburgh district, Pennsylvania

669,817 and that of Allegheny County as 1,374,310. Contiguous to the city are nearly 200 industrial towns, with popula-


*A.* FACE OF THE PITTSBURGH COAL SEAM

Photograph by United States Bureau of Mines.

*B.* RIVER TRANSPORTATION, PITTSBURGH DISTRICT

Photograph from United States Engineer Office.

tions varying from a few hundred to 54,000. Except in the making of rails, in which Chicago leads, Pittsburgh exceeds other cities in the production of steel. Although formerly all the iron ore used in the East was brought to Pittsburgh, with its plentiful supply of coal and coke, it is now the tendency to transport the ore, coal, and coke to other great centers of population for the manufacture and distribution of iron and steel. Nevertheless costly improvements and expansions of the existing steel works of the Pittsburgh district continue.

Politically the Pittsburgh district is Allegheny County. Industrially and commercially the district includes the counties adjacent to Allegheny.

The topography of Pittsburgh and its environs is varied. The region is one of maturity in the erosion cycle. The principal streams have eroded their valleys to a fairly uniform grade, and the smaller branches have cut the uplands into narrow ridges. Altitudes range from 780 to 1,510 feet (238 to 460 meters). Much of the residential portion of the city of Pittsburgh is built upon broad, flat terraces that represent abandoned stream channels. The local topographic conditions have necessitated the building of expensive streets, boulevards, inclines, tunnels, and bridges. Six trunk railroads and 19 industrial and terminal switching lines serve the district, in addition to the river transportation. Trolley lines run between the city and the suburbs, and the network of good hard-surfaced roads is traversed by scheduled motor buses. Three main highways converge at Pittsburgh—the William Penn, Lincoln, and William Flinn. There is a vast distribution of coal, coke, oil, iron and steel, cement, and merchandise from this center.

## GEOLOGY AND STRUCTURE

The hard rocks that crop out in the Pittsburgh district are of Carboniferous age. Outwash glacial deposits of gravel, sand, etc., occur on old river terraces. Recent deposits of unconsolidated silt, clay, and gravel have been laid down on flood plains.

The following section shows the thickness of the Carboniferous formations and the relative stratigraphic positions of the members they include:

104899—32——2

| | Feet | Meters |
|---|---|---|
| Permian: | | |
| Dunkard group | 300+ | 91+ |
| Washington coal. | | |
| Waynesburg "A" coal. | | |
| Waynesburg sandstone. | | |
| Pennsylvanian: | | |
| Monongahela formation | 310–400 | 94–122 |
| Waynesburg coal. | | |
| Uniontown coal. | | |
| Benwood limestone. | | |
| Sewickley coal. | | |
| Redstone coal. | | |
| Pittsburgh coal. | | |
| Conemaugh formation | 600 | 183 |
| Connellsville sandstone. | | |
| Morgantown sandstone. | | |
| Ames (crinoidal )limestone. | | |
| Saltsburg sandstone. | | |
| Mahoning sandstone. | | |
| Allegheny formation | 280 | 85 |
| Upper Freeport coal. | | |
| Bolivar fire clay. | | |
| Lower Freeport coal. | | |
| Upper Kittanning coal. | | |
| Middle Kittanning coal. | | |
| Lower Kittanning coal. | | |
| Brookville-Clarion coal. | | |
| Pottsville formation | 150 | 46 |
| Homewood sandstone. | | |
| Mercer shale. | | |
| Connoquenessing sandstone. | | |
| Mississippian: | | |
| Mauch Chunk formation | 150 | 46 |
| Greenbrier limestone. | | |
| Loyalhanna limestone | 60± | 18± |
| Pocono formation | 340+ | 104+ |

In the vicinity of Pittsburgh the outcropping rocks are mainly those of the Conemaugh and Monongahela formations—the Conemaugh north of Pittsburgh and the Monongahela south of Pittsburgh. Most of Greene County and the southern half of Washington County are underlain by Permian beds. The Allegheny formation (Pennsylvanian) occupies large areas only north of Beaver and Butler. Elsewhere it crops out in narrow belts along the streams of the Conemaugh outcrop area and in the more folded area east of Connellsville and Uniontown. Pottsville and older rocks are exposed only in the latter area.

Structurally the Pittsburgh district lies in an extremely flat major syncline whose axis has a very low southwesterly pitch and in which the dips average only a few tens of feet to the mile. Northwest and west of the district equally low dips prevail. East and southeast of the district the dips are steeper, and the intensity of folding increases rapidly east of Connellsville and Uniontown.

Superimposed on the major syncline are a number of northeastward-trending anticlines and synclines that have influenced the outcrop and extent of the coal beds. Some of the larger streams of the district cut across the structure and increase the accessibility of the coals for mining.

## MINERAL RESOURCES

The most valuable mineral resources of the Pittsburgh district are coal, oil, natural gas, clay, and limestone.

### COAL

The Pittsburgh district is underlain by many coal beds but only three are of economic importance at the present time—the Redstone, the Pittsburgh, and the Upper Freeport. Some of the other beds have been mined and used locally. The Pittsburgh bed is by far the most valuable. The Middle Kittanning and Lower Kittanning coals are important reserves for the future but have not yet been developed because of the great depth at which they lie.

#### Pittsburgh Coal Seam

The Pittsburgh coal seam lies at the base of the Monongahela formation. It underlies nearly the whole of Washington and Green Counties and considerable portions of Allegheny, Westmoreland, and Fayette Counties. It is the most famous and most remarkable high-volatile gas and coking coal known. It is not only the most valuable bituminous coal bed in Pennsylvania, but also in Ohio and northern West Virginia. It ranges in thickness from 4 feet (1.2 meters) to 15 feet (4.6 meters) and averages about 7 feet (2.1 meters). It is generally thicker in the east and south and thins to the north and west. Plate 1, A, shows a typical face of this seam.

The chemical composition of the coal shows a progressive change across the district from east to west; the volatile matter increases from 32 to 40 per cent, the ash content from 6 to 10 per cent, and the sulphur from less than 1 to more than 3 per cent. The change in chemical composition is accompanied by a change in physical character. In the eastern area the coal is soft and friable, and in the western area it is hard and lumpy. The harder coal is extensively used for household fuel. The low-ash and low-sulphur coal of the eastern area is of superior quality for use as gas coal in steel making and for coking. The Connellsville region was early famous for the superior quality of its coke. Coking in beehive ovens commenced here a cen-

tury ago, and the product was widely shipped. At present there are 25,000 serviceable ovens, but not one-tenth of them are active because by-product coke ovens have largely supplanted the beehive ovens.

### Coal Reserves and Production

The Pennsylvania Geologic Survey estimates the following quantities of recoverable coal in the Pittsburgh district:

| | Tons | Metric tons |
|---|---|---|
| Pittsburgh | 8,090,000,000 | 7,339,000,000 |
| Redstone | 414,000,000 | 376,000,000 |
| Freeports | 5,665,000,000 | 5,139,000,000 |
| Kittannings | 986,000,000 | 894,000,000 |
| Other seams | 4,005,000,000 | 3,633,000,000 |
| | 19,160,000,000 | 17,381,000,000 |

The annual production of the five counties comprising the Pittsburgh district during the years 1924 to 1928 was:

| | Tons | Metric tons |
|---|---|---|
| 1928 | 80,995,000 | 73,478,000 |
| 1927 | 66,400,000 | 60,237,000 |
| 1926 | 92,728,000 | 84,121,000 |
| 1925 | 81,908,000 | 74,305,000 |
| 1924 | 79,419,000 | 71,948,000 |
| Average | 80,290,000 | 72,837,000 |
| Average Pennsylvania | 133,511,000 | 121,118,000 |
| Average United States | 567,797,000 | 515,096,000 |

The district, therefore, produces three-fifths of the Pennsylvania coal output and one-seventh that of the entire United States.

### Mining Methods

Most of the coal mined from the Pittsburgh bed has been obtained through drift mines. Shaft mines have not yet been extensively developed. The average mine produces less than 2,000 tons (1,814 metric tons) a day, although there are a number of 4,000-ton mines and a few projected to 10,000 tons a day. The value of the coal in the ground in Pennsylvania has promoted conservation of coal, and the recovery is usually around 85 per cent. The general plan of operation is the room-and-pillar system, with double entries from which the rooms are driven. In recent years there has been a tendency toward the adoption of the panel room and pillar method; also the block system, which admits of concentrated mining within a relatively small section of the mine.

### Methods of Preparation

In the Pittsburgh district coal from the Pittsburgh and Freeport beds is being cleaned in 10 plants at a total rate of 5,000 tons (4,536 metric tons) an hour. This total is more than half of the amount of coal cleaned in all plants preparing bituminous coal in western Pennsylvania. Approximately four-fifths of this coal is washed with water; the remainder is cleaned pneumatically. A large part of the cleaned coal is used for metallurgical purposes—for blast-furnace and cupola coke. Much of the cleaned coal is sold also to industrial and domestic consumers.

## OIL AND GAS

Oil has been found in many pools in the Pittsburgh district. It is of paraffin base and has a gravity of 40° to 43° Baumé. Oil was discovered many years ago, and some wells yielded as much as 100 barrels a day. Many of them are still being pumped, but their present daily average is very small.

Natural gas ranks second among the natural resources of Pennsylvania and is of great importance in the Pittsburgh district. It has been one of the largest factors in the development of the iron and steel and glass industries and, because clean and easily handled, is an ideal fuel. It has twice the heating value of manufactured gas and costs less.

During years past a great many oil and gas pools have been developed in the district. The number of sands in which oil and gas have been found varies in different sections. The oil and gas occur in porous sandstones of Pennsylvanian, Mississippian, Devonian, and Silurian age. In a general way the sands in which some oil or gas has been found range in depth from about 1,000 to more than 3,900 feet (305 to 1,190 meters) below the base of the Pittsburgh coal. The production has been dwindling, but there are possibilities that additional supplies of oil or gas will be found in deeper sands, notably those of Oriskany and Medina age, which lie at depths of at least 6,500 and 8,000 feet (1,980 and 2,440 meters). Several wells have been drilled to a depth of more than 7,300 feet (2,225 meters) below the Pittsburgh coal without striking commercial amounts of oil or gas.

## OTHER MINERAL RESOURCES

There are in the district large deposits of bedded clay and shale, which are used for brickmaking; limestone, which is used for flux, road metal, agricultural lime, and railroad ballast; sandstone, sand, and gravel. Sand and gravel are largely dredged from the rivers, which contain almost inexhaustible supplies.

# OPERATIONS AT A MODERN COAL MINE IN THE PITTSBURGH BED

## WARDEN MINE

*Situation and area.*—The pit mouth of the Warden mine is half a mile (0.8 kilometer) west of Douglass station of the Pittsburgh, McKeesport & Youghiogheny Railroad. The mine lies between the Youghiogheny and Monongahela Rivers in Elizabeth Township, Allegheny County.

The surface area of the property is 7,800 acres (3,156 hectares), and the coal-bearing area remaining is 2,760 acres (1,117 hectares). The coal bed averages 10,100 tons (9,162 metric tons) to the acre, of which 8,079 tons (7,328 metric tons) is recovered.

*Topography and overburden.*—Within the property limits the altitude of the surface ranges from 770 to 1,325 feet (235 to 404 meters).

The range of cover is 0 to 530 feet (162 meters); in working sections 200 to 530 feet (61 to 162 meters). The Monongahela formation, which is prevailingly calcareous, is 310 to 400 feet (94 to 122 meters) in thickness. A massive limestone 140 feet (43 meters) thick lies about 100 feet (30 meters) above the coal, and thin beds of limestone occur both above and below this main member. Considerable shale is interbedded with the limestone. There are a few coarse sandstones near the top and bottom of the formation; also four beds of coal, mostly thin and worthless.

The Dunkard group, above the Monongahela formation, consists chiefly of coarse friable sandstone and sandy shale, though many thin beds of limestone and several thin beds of coal are also present.

*Coal bed.*—The coal and the draw slate over it are very uniform. The slate is weak and is taken down in mining. A few clay veins and bottom rolls occur.

*Sampling and analysis.*—As the seam is so uniform, no bench samples have been taken for over two years. Control samples embracing raw coal, clean coal, refuse, and sludge are taken in the washery at regular and frequent intervals.

An average proximate analysis of the raw coal is as follows:

| | Per cent |
|---|---|
| Moisture | 1.2 |
| Volatile | 34.5 |
| Fixed carbon | 53.8 |
| Ash | 10.5 |
| Sulphur | 0.95 |
| British thermal units | 13,670 |

Fusion temperature, 2,575° F., or 1,413° C.

*Type of opening, extent of working, and equipment.*—The opening is a drift. The haulage distance from pit mouth to the nearest active workings is 1 mile (1.6 kilometers); to the most remote active workings, 4 miles (6.4 kilometers).

The mining equipment and practice are as follows:

Lamps: Edison battery lamps for miners; Wolf flame safety lamps for mine officials, cutters, and shot firers.

Cutting machines: Short wall, bottom-cutting arc wall, and combination cutting and shearing machines. The last two cut from the track.

Drills: Rotary air drills for blasting, with air supplied by portable and stationary compressors; electrically-driven drills mounted on combination cutting and shearing machines.

Explosives: None but permissible (approved by United States Bureau of Mines).

Blasting practice: All done by competent shot-firers; a battery and electric detonators are used.

Loading machines: Joy, Jeffrey 44–C, and pit-car loaders.

Mine cars: Solid end, all-steel rotary-dump cars of 4-ton capacity, with tapered roller bearings.

Locomotives: Main haulage, 13 and 20 ton trolley, open type; gathering, 8-ton cable-reel, and 5 to 8 ton battery; permissible types.

*Rock dusting.*—To the end of 1930, 82 miles (132 kilometers) of single entry had been treated with 3½ pounds of rock dust per foot of entry (0.5 kilogram per meter) in one application (average). The average of the dust in the entries rock dusted is 84 per cent incombustible. On each shift 1,800 feet (549 meters) of entry is rock dusted, and the interval between successive applications is 3 to 12 months.

*Employees and production.*—The following table shows the number of employees and the production for each class:

| | Men | Coal | | | |
|---|---|---|---|---|---|
| | | Total | | Per man shift | |
| | | Tons | Metric tons | Tons | Metric tons |
| Mechanical loading | 129 | 1, 558 | 1, 413 | 12. 08 | 10. 95 |
| Pickmen and loaders | 767 | 6, 542 | 5, 935 | 8. 53 | 7. 74 |
| All other classes (excluding cleaning plant and tipple) | 336 | | | | |
| | 1, 232 | 8, 100 | 7, 348 | 6. 57 | 5. 88 |
| Total, including cleaning plant and tipple | 1, 319 | 8, 100 | 7, 348 | 6. 14 | 5. 50 |
| Total, bank loss deducted | 1, 319 | 7, 600 | 6, 894 | 5. 76 | 5. 22 |

## WARDEN WASHERY

The preparation plant is a combined tipple and washery. The coal larger than 4 inches (10 centimeters) is hand picked; the smaller coal is cleaned by the Rheolaveur process.

The tipple handles 1,000 tons (907 metric tons) of run of mine coal an hour, and the cleaning plant handles 500 tons (454 metric tons) of the coal smaller than 4 inches (10 centimeters). The cleaning plant works on double shift.

*Source of coal.*—The Warden mine produces 8,000 to 8,500 tons (7,257 to 7,711 metric tons) a day, and the Ocean mine, whose output is also cleaned at this washery, produces 3,000 to 3,600 tons (2,722 to 3,266 metric tons) a day. An aerial tram was designed to carry the raw coal smaller than 4 inches (10 centimeters) from the Ocean mine to the cleaning plant and to carry refuse from the cleaning plant on the return trip. On double-shift operation the capacity of the tram is 2,000 tons (1,814 metric tons) a day. This tram is 6,000 feet (1,829 meters) in length and was designed for 100 tons (90.7 metric tons) an hour of coal and refuse from the washery.

*Screening raw coal, washing, and mixing clean coal.*—The run of mine coal is passed over 4-inch (10-centimeter) shaker screens; the screenings are sent to the cleaning plant, and the lumps larger than 4 inches are hand picked. Mechanically cleaned coal is sized as follows: 2 by 4 inch, 1 by 2 inch, ⅜ by 1 inch, and smaller than ⅜ inch (5 by 10, 2.5 by 5, 0.9 by 2.5, and smaller than 0.9 centimeter). Of the cleaned coal less than 6 per cent is ⅜ by 1 inch (0.9 by 2.5 centimeters) steam coal; the remainder is metallurgical coal. These sizes and grades can be mixed in any desired proportions.

*Power, water, and employees.*—Purchased electric power is used, and the consumption is 1.65 kilowatt-hours per ton (1.5 kilowatt-hours per metric ton) of run of mine coal handled. There is 5,000 gallons (18,927 liters) of water in circulation. The normal operating crew for one shift operation is 8 pickers and 46 operators, mechanics, and others in the cleaning plant.

*Sampling.*—The daily control samples of raw coal, clean coal, and refuse are taken at 20-minute intervals during the shift. Separation and screen tests are made constantly on all units and all products. The normal laboratory crew for two-shift operation consists of four men—a chief chemist, an assistant chemist, and two samplers.

*Results of cleaning.*—The average percentages of sink and ash in the sink in cleaned coal are, for metallurgical coal, 0.5 per cent sink with 45 per cent ash; for steam coal, 3 per cent sink with 42.2 per cent ash. The loss of coal is 6.6 per cent.

## MANUFACTURE OF IRON AND STEEL

Pittsburgh's first iron was made in a charcoal blast furnace in the Shadyside district (now a residential area) in 1792. The ore was mined on the western slope of the Allegheny Mountains. This furnace worked only two years. The second furnace was built in 1859, on the South Side. Now Allegheny County has 45 blast furnaces, 245 open hearth furnaces, 15 converters, and 52 rolling mills and steel works. The normal annual production exceeds 6,000,000 tons (5,443,000 metric tons) of iron, 8,000,000 tons (7,257,000 metric tons) of steel ingots and castings, and 6,000,000 tons (5,443,000 metric tons) of rolled products, but the capacity of the works is much greater than this. In addition, there is a large tonnage of aluminum, copper, lead, tin, zinc, and alloys of these metals produced or worked.

### OPERATIONS OF A SELF-CONTAINED STEEL COMPANY

The Aliquippa works of the Jones & Laughlin Steel Corporation extends for 4 miles (6.4 kilometers) along the Ohio River about 20 miles (32 kilometers) northwest of Pittsburgh. This plant manufactures a comprehensive variety of steel products from raw materials.

The firm of Jones & Laughlin was established in 1850, and from a small beginning the present corporation has reached fourth place in the list of steel producers of the United States, achieving that position by growth alone, without bringing in any new interests, and unaffected by the combinations and consolidations that have taken place, especially in the last 30 years.

The corporation is fully self-contained in that it owns and operates coal and iron-ore mines, limestone quarries, railroads that connect with trunk systems, lake and river steamers, by-product coking plants, blast furnaces, open-hearth furnaces, bessemer converters, and mills of various types in which are produced a widely diversified group of steel products. These plants have an annual ingot capacity of 3,420,000 gross tons (3,474,000 metric tons) and in normal times employ 23,000 men.

The Aliquippa works is supplied with raw materials—iron ore, coal, and limestone—by rail and water transportation. Iron ore from the corporation's mines in Minnesota and Michigan is brought by its own steamships on the Great Lakes to Lake Erie ports and thence by rail to the works. The coal used in the corporation's manufacturing processes is brought down the Monongahela River in modern steel barges by corporation towboats from the mines of its subsidiaries the Vesta Coal Co. and the Shannopin Coal Co., and the limestone by rail from its subsidiary the Blair Limestone Co.

In 1927 Jones & Laughlin instituted the first railroad-car ferry service on the Monongahela and Ohio Rivers (pl. 1, *B*), by means of which its Aliquippa and Pittsburgh works are as effectively connected as its plants on the north and south sides of the Monongahela River in Pittsburgh.

At Aliquippa there are 203 by-product coke ovens with an annual capacity of 1,500,000 tons (1,361,000 metric tons) of coke; by-product and benzol plant for recovery of ammonium sulphate, fuel tar, fuel gas, and fuel oil; 5 large blast furnaces, with a capacity of 1,488,000 gross tons (1,511,000 metric tons) of pig iron annually; 4 Talbot open-hearth furnaces and 3 bessemer converters, with a steel-ingot capacity of 1,420,000 gross tons (1,442,000 metric tons); one 44-inch (111-centimeter) blooming mill with ten 4-hole soaking pits; 1 continuous billet and bar mill; 1 continuous sheet bar and skelp mill; one 10-inch (25-centimeter) skelp mill; one 14-inch (35-centimeter) straightaway merchant mill; 2 continuous wire-rod mills; 2 patent annealing furnaces; 393 wire-drawing blocks; 3 wire zinc-coating pans; 110 barbed-wire machines; 8 field-fence machines; 227 wire-nail machines; 4 staple machines; 69 sheet and pair furnaces; 32 hot black-plate (tin) mills; 5 Mesta pickling machines; 12 box-annealing furnaces (including 1 tunnel furnace); 10 trains of cold rolls; 31 tinning stacks; 4 butt-weld pipe furnaces; 3 lap-weld pipe furnaces and 2 pipe zinc-coating units; 2 seamless-tube mills for making seamless pipe from 2⅜ to 13⅜ inches (5.9 to 32.9 centimeters), together with a 30-inch (70-centimeter) mill for manufacturing rounds from which the seamless pipe is made. These departments are all complete with finishing and shipping facilities. There is also complete equipment of auxiliary plants, utilities, and facilities such as docks, coal and ore handling plants, steam and electric plants, pumping plants, machine shops, repair shops, laboratories, warehouses, mill transportation facilities, and mill office buildings.

The Jones & Laughlin Steel Corporation has pioneered in the transportation of steel products by water from Pittsburgh down the Ohio River to Cairo, up the Mississippi River to Minneapolis, and down that river to New Orleans. The tows, consisting of a large steamer and as many as a dozen barges, carry as much as 12,000 tons (12,192 metric tons) of varied steel products. If the materials require protection from the weather they are stowed in covered barges. More than 120 Jones & Laughlin tows have been sent the 1,206 miles (1,940 kilometers) from Pittsburgh to Memphis, Tennessee, or the 1,953 miles (3,143 kilometers) to New Orleans. Manufactured steel products of all kinds are delivered to customers in the West, South, and Southwest by river and rail through a system of modern steel

gondola and box barges, which transport the products to the Cincinnati and Memphis warehouses of the corporation, as well as to Louisville, Evansville, St. Louis, New Orleans (where the firm has a fabricating plant), and other river ports, from which large tonnages of these products are transferred to railroads and sent on to ultimate destinations many hundreds of miles from the rivers.

## ACKNOWLEDGMENTS

Thanks are given to George H. Ashley, State geologist, and R. W. Stone, associate geologist, of Pennsylvania; C. R. Fettke, professor of geology in the Carnegie Institute of Technology; C. E. Lesher, executive vice president, and others of the Pittsburgh Coal Co.; and J. G. West, jr., assistant general manager, and W. T. Mosman, advertising manager of the Jones & Laughlin Steel Corporation, for their comments and help in preparing this article.

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# INDIANA OOLITIC LIMESTONE

By G. F. Loughlin

ABSTRACT

The annual production of Indiana oolitic limestone constitutes 40 per cent of the total natural building stone and 80 per cent of the limestones quarried for building stone in the United States.

The limestone is of Mississippian age and attains 100 feet (30 meters) in maximum thickness. It has a fine to coarse grained granular texture and is commonly cross-bedded. It consists of Foraminifera and small fragments of dwarf crinoid stems and mollusks with poorly defined oolitic coatings in a matrix of calcite. In the typical building stone both the fragments and the matrix have recrystallized into interlocking grains of calcite, but a considerable degree of porosity remains.

Stylolites if not too conspicuous are permitted in the less expensive grades of building stone. Thin calcite veinlets and shells filled with glassy calcite decrease the value of the stone.

Major fractures that have been enlarged by solution above ground-water level and filled with mud are called "mud seams." The stone within the zone of these "mud seams" has been oxidized to a buff color, but differences in permeability have caused irregularities in the distribution of buff and gray stone.

The oolitic limestone contains 95 to 98 per cent of calcite. Chemical tests and observation of the older buildings containing the stone show that maximum exposure to rain water corrodes the surface to a depth of 1.6 millimeters in 50 years.

The strength is greatly increased by seasoning. The average crushing strength of commercial stone is between 6,000 and 7,000 pounds to the square inch (422 to 492 kilograms to the square centimeter). The average specific gravity is 2.3. Absorption averages 5 per cent by weight and 12 per cent by volume; porosity averages 16 per cent by volume. Injury by frost is negligible in seasoned stone that is used with ordinary precautions.

The stone is quarried by channeling, and the large channeled blocks are cut into mill blocks that range from 6 to 12 feet (1.8 to 3.6 meters) in length and are about 4 feet (1.2 meters) square. These blocks are reduced to slabs by gang saws and worked into final shapes by planers and a number of power-driven tools.

The building stone is classified into 13 different grades, which are listed at the end of the report.

## HISTORY, PRODUCTION, AND CONSUMPTION

The Indiana oolitic limestone, by far the most used building stone in the United States, is quarried in Lawrence and Monroe Counties, south-central Indiana. (See fig. 5.) Although used locally to a slight extent as early as 1840, it did not begin to attract general attention until 1870, when the Lawrence County courthouse at Bedford was erected. By 1880 the stone had been introduced in Chicago and New York, and by 1895 it had been shipped to more distant points and small quantities had been exported.

The ease and cheapness of quarrying and finishing the stone allowed it to compete with the more favorably situated and

previously more prominent building stones, and this all-important fact, together with the relief and contrast that its light-buff and gray colors gave from the more somber brown sandstones and red granites, was a great aid in bringing about a change in fashion favoring light-colored stone for building.

Records of shipments since 1917 show that the stone is used in 43 of the 48 States including those on the Pacific coast, as well as in Canada. Its annual production represents about 40 per cent

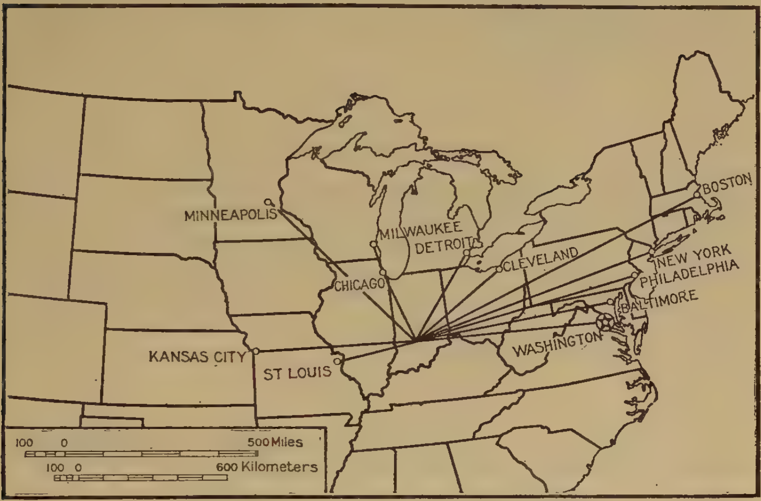


FIGURE 3.—Map showing location of Indiana oolitic limestone district and the principal markets

of all kinds of natural building stone and about 80 per cent of all limestones in the United States. The principal consuming States, which account for about 80 per cent of its sales, are Indiana (20 per cent), Illinois (17 per cent), New York (11 per cent), Michigan, Ohio, and Pennsylvania (7 per cent each), and Massachusetts, Minnesota, New Jersey, and Wisconsin (2 per cent each). Canada also consumes about 2 per cent, and the District of Columbia is at present a large consumer because of the Federal Government's extensive building program. The principal markets in these States are shown in Figure 3.

The growth of the industry since 1901, when reliable statistics of production [1] became available, is shown by the curves in Figure 4.

[1] Coons, A. T., chapters on stone in annual volumes of Mineral Resources of the United States, 1901–1930 (U. S. Geol. Survey, 1901–1924; U. S. Bur. Mines, 1925–1930).

For many years the prevailing demand was for buff-colored stone of fine, even grain, as it was supposed that other grades of the stone were less durable. Much good stone was accordingly wasted or sold as riprap or other by-products; but recent investigations have shown that there are no noteworthy differences, except in color and texture, in the more abundant grades of stone, and sales of the stone have become much more diversified. The by-products include oolitic stone for flux, riprap, rubble, glass making, soil sweetening, and sundry other uses. The hard (Mitchell) limestone that overlies the oolitic stone is used for crushed stone.

## GEOLOGY

### OCCURRENCE

The Indiana oolitic limestone, which is 100 feet (30 meters) in maximum thickness is exposed with few interruptions from Greencastle, Indiana, southward into Kentucky, but the quarries are mainly grouped in north-central Indiana. (See fig. 5.) The formation lies horizontally or dips west at very low angles (fig. 6) and is exposed along the margins of valleys or on the summits of low hills and ridges.

### STRATIGRAPHY

The limestone is of Mississippian age, and its stratigraphic position is shown in the following section:

*Section of Carboniferous formations in north-central Indiana*

| | | Feet | Meters |
|---|---|---|---|
| Pennsylvanian ("Coal Measures"): | | | |
| Sandstone, shale, and limestone (thickness from Hanover to Vincennes) | | 800 | 244 |
| Mansfield sandstone | | 0–280 | 0–85 |
| Unconformity. | | | |
| Mississippian: | | | |
| Chester group: | | | |
| Limestone, sandstone, and shale; thickest in southern Indiana | | 43–600 | 13–183 |
| Limestone at base | Mitchell limestone | 150–400 | 46–122 |
| Chester or Meramec group: | | | |
| St. Genevieve limestone | | | |
| Meramec group: | | | |
| St. Louis limestone | | | |
| Spergen limestone (Salem limestone of Indiana Department of Geology and Natural Resources; Indiana oolitic limestone (Bedford oolitic limestone) of the trade) | | 20–100 | 6–30 |
| Warsaw ("Harrodsburg") limestone | | 60–140 | 18–43 |
| Osage ("Knobstone") group | | 40–650 | 12–198 |
| Rockford ("Goniatite") limestone | | 1–3 | 0.3–0.9 |

The formation has been given several names in different places and at different times. The name Spergen limestone was adopted by the United States Geological Survey in 1904 because fossils had been collected from the formation at Spergen Hill, near Salem, Indiana, by James Hall in 1858; but Cumings in 1901 had proposed the name "Salem limestone" as more repre-

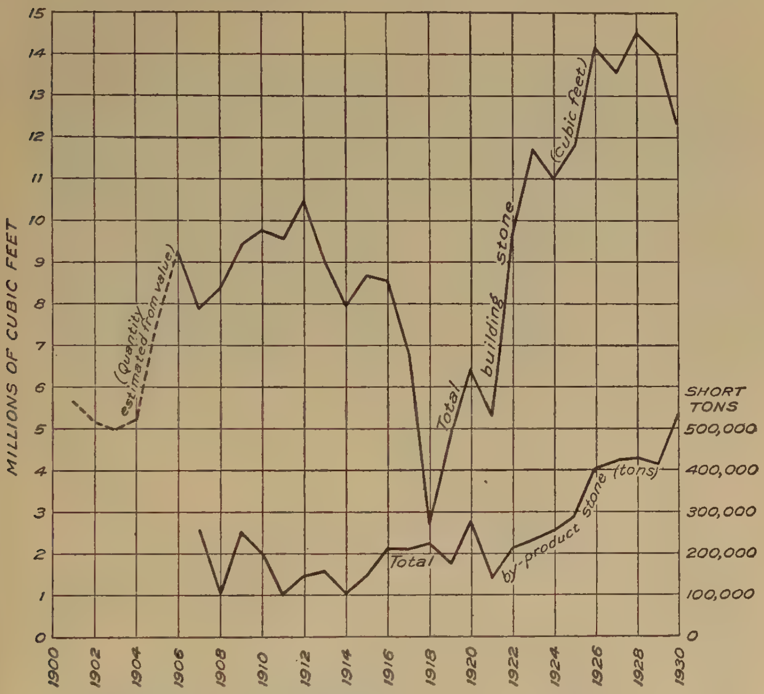


FIGURE 4.—Production of Indiana oolitic limestone, 1901–1930

sentative, and that name was adopted by the Indiana Department of Geology and Natural Resources. The stone industry prefers the more comprehensive name "Indiana oolitic limestone," which applies equally well to stone from any of the quarry districts and other parts of the formation. The limestone has also been called the Bedford oolitic limestone.


FIGURE 5.—Map showing exposed extent of Indiana oolitic limestone in Indiana. (From map published by Indiana Department of Geology and Natural Resources in 1901)

*A*. PART OF A QUARRY IN THE INDIANA LIMESTONE

Showing typical mud seams developed along steeply inclined fissures. From U. S. Geol. Survey Bull. 811, 1930.

*B*. ERODED SURFACE OF INDIANA OOLITIC LIMESTONE

Exposed after removal of residual soil by hydraulicking. From U. S. Geol. Survey Bull. 811, 1930.

## CHARACTER OF INDIANA OOLITIC LIMESTONE

### TEXTURE

The Indiana oolitic limestone has a pale to medium buff color above ground-water level and a gray or bluish-gray color below. It has a granular texture and commonly a cross-bedded structure. The grain of the usual salable stone ranges from fine (less than 1 millimeter in diameter) through medium (1 to 3 millimeters) to coarse (greater than 3 millimeters). Some stone contains considerable very fine grained or dense material, either as a matrix for the visible grains or in layers or streaks between granular layers. The constituent grains include an abundance of Foraminifera and small fragments of crinoid stems with poorly defined oolitic coatings. The coarser-grained varieties include distinct fragments of brachiopod, pelecypod, and gastropod shells, Bryozoa, and corals. Ostracodes are said to be characteristic of the stone, but few if any have been noted in specimens examined microscopically by the writer. Layers or small lenses of unusually well developed oolitic grains are present in both the coarser-grained and the fine-grained and dense stone.

The granular cross-bedded stone of commercial value grades locally into calcareous "mudstone" or marl. Owing to changing conditions during deposition the marl is found above the cross-bedded stone in some places, below it in others, and both above and below in still others.

Beede concluded that the stone of commercial quality forms a series of great lenses embedded in the marl, which commonly contains considerable bituminous matter derived from decaying organisms. Surface exposures are insufficient for separate mapping of the typical commercial limestone and the marly material,

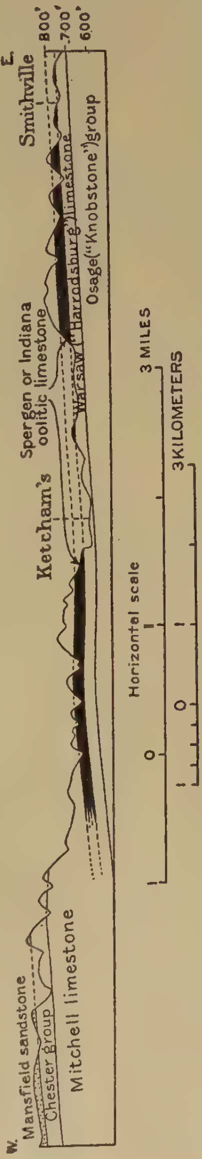


FIGURE 6.—East-west section through Smithville, Indiana, showing westward dip of the Indiana oolitic limestone and its relation to overlying and underlying strata. (From U. S. Geol. Survey Bull. 811, fig. 24, 1930)

and Figure 5 shows the extent of the formation as a whole. Prospecting with the core drill is necessary to determine undeveloped areas of commercial stone.

In the typical varieties of Indiana oolitic limestone the shell fragments and oolitic skins are largely converted into crystalline grains of calcite, which preserve the original markings but not the original structure. The matrix, in growing as enlargements of these crystalline grains, has formed interlocking contacts characteristic of the grains of marble. Where the matrix has completely filled the pores the stone has the properties of marble, but for the most part a considerable degree of porosity remains. In the more marly varieties of the stone, which are avoided by quarrymen, this process of crystallization took place only to a minor degree, and the soft, chalky character of the matrix remains. In the examination of stone from undeveloped ledges the character of the matrix, whether recrystallized and sound or still chalky and subject to rapid disintegration, is of critical importance as an indication of commercial value.

## SPECIAL FEATURES

*Cross-bedding.*—Experience has shown that in stone of commercial quality the cross laminae are practically free from partings or marly film. A few quarries abandoned years ago in outlying parts of the district contained some stone that tended to split along cross laminae after exposure, but rarely if ever is such a defect noted in stone that has been shipped in recent years.

*Top rock.*—It is a common experience that the uppermost part of the formation, commonly the first two levels or "floors" of the quarry, contains unusually hard stone, called "top rock," that consists of varying mixtures of extra fine grained and extra coarse grained stone, in which partings and marly streaks may be present and short fractures are especially abundant. Similar conditions have been found at a few places in the lowest floors of quarries, and rarely within one or more of the middle floors. Much of this "top rock" has been discarded, but in some of it the grain is so nearly uniform and the fractures are so scarce and so well sealed with inconspicuous calcite veinlets that the stone is of commercial quality. Its efficient handling is likely to be one of the quarryman's major problems. It may be so full of fractures or visible marly streaks that it is only fit for use as rubble, or it may appear to be sound but contain some marly streaks which escape detection at first but which induce splitting or scaling later. Adequate seasoning is therefore essential to the determination of the quality of this stone.

*Stylolites.*—Another feature with which quarrymen must contend is the occurrence of stylolites, or "crowfeet." These

are especially conspicuous near the top and bottom of the formation, and in several quarries a prominent stylolite separates the hard "top rock" from the usual commercial grades. Others may occur within the middle part of the formation. These stylolites consist of black, bituminous shaly matter with irregularly distributed pyrite. The prominent stylolites that contain shaly layers 1.5 millimeters (1/16 inch) or more thick so weaken the stone that it may split along the stylolite during sawing or finishing, or during subsequent exposure. Well-seasoned stone that contains stylolites and withstands quarrying and milling is included in "Old Gothic" stock, which consists of all varieties and colors of the stone and is derived mainly from quarry blocks that for one reason or another are excluded from the regular commercial grades. A few quarry prospects have never passed the development stage because of the abundance of prominent stylolites. A few others, after a considerable production of good stone, have been extended into places where stylolites are so abundant that the quarries had either to be abandoned or to be developed in different directions.

*"Glass seams" and "spots."*—Other irregularities include thin veinlets of dense calcite and "glass seams" and "spots" of colorless calcite. The veinlets of dense calcite represent the filling of local irregular contraction cracks that were developed during the deposition of the formation. These cracks have been completely sealed by the veinlets, which affect the appearance of the stone only at rather close range. The "glass seams" or colorless veinlets have resulted from the partial to complete filling of fractures caused by regional disturbance. Partly filled fractures may open during quarrying or milling, and any finished blocks containing them are likely to split eventually if used in places that are subject to frequent seepage of water and consequent frost action. The "spots" are due to the filling of comparatively large fossil shells. Fractures or fossil shells thoroughly sealed by glassy calcite affect only the appearance, and stones containing them, like those containing inconspicuous stylolites, are commonly graded below similar stone that is free from them.

*Major fractures and mud seams.*—The fractures thus far mentioned are mostly minor members of a system that was developed during uplift at the end of Carboniferous time. Most of the larger fractures are simple fissures, but some are accompanied by a few inches of displacement or faulting. After erosion had brought the formation above ground-water level, the circulation of water along these fissures dissolved their wall rocks and enlarged them into chasms or caverns of considerable size, which as they grew became filled with reddish mud derived from residual soil. They are called "mud seams." (See pl. 2, *A*.)

*Relation of buff to gray stone.*—Water percolating from the enlarged fissures through the porous stone oxidized its organic coloring matter and any finely divided pyrite present and developed the buff color that is typical of the stone above ground-water level. There may be considerable irregularity in the contact between the buff stone and the original bluish-gray stone near ground-water level, owing to differences in permeability in the stone. Where the overlying Mitchell limestone is comparatively thick and the ground-water level is in the upper part of the oolitic limestone, impervious shale beds at the base of the Mitchell limestone protected the underlying stone from permeation, and local masses of bluish-gray stone are found within the zone of buff stone, as shown in Figure 7.

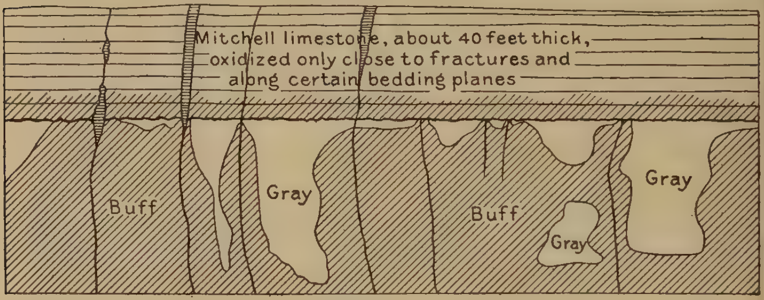


FIGURE 7.—Wall of a quarry in the Indiana limestone west of Bedford, Indiana, (1917), showing relation of buff color to fissures. An impervious bed at the top of the formation has resisted oxidation and retained its original gray color. Water descending through this bed along fissures has spread into the underlying part of the formation, gradually oxidizing it to a buff color, but large masses with the original gray color still remain between fissures. (From U. S. Geol. Survey Bull. 811, fig. 24, 1930)

*Chemical composition.*—A large number of chemical analyses shows that 95 to 98 per cent of the oolitic limestone is calcite, and that magnesium carbonate rarely exceeds 1.5 per cent. Silica ranges from 0.20 to 0.95 per cent, alumina from 0.50 to 0.75 per cent, iron oxides from 0.05 to 0.20 per cent, and total sulphur (in pyrite and organic matter) from 0.25 to 0.85 per cent. There is a small but persistent excess of CaO over that necessary for calcite and dolomite, and this excess may be present in organic matter.

*Physical properties.*—Owing to conflicting opinions regarding the relative merits of the different commercial grades of stone, which are based on color and texture, a large number of physical

tests were made by the United States Bureau of Standards.[2] The results show that although there is considerable range in physical properties within any one grade, there is little or no noteworthy difference among the grades most commonly used. Differences within any one grade may be due to original differences in porosity and in the degree of crystallization of the matrix, but also to the differences in degree of seasoning. A newly quarried stone saturated with quarry water or "sap" may have a crushing strength of only 3,000 pounds to the square inch (211 kilograms to the square centimeter), whereas the same stone after thorough seasoning will have a crushing strength of 6,000 to 7,000 pounds to the square inch (422 to 492 kilograms to the square centimeter). In general, the less the porosity the more thorough the cementation and the greater the specific gravity, crushing strength, and transverse strength. Specific gravity may serve, therefore, as an index of the general physical character. The average stone shipped from the district has a specific gravity of 2.3, or a weight of 144 pounds to the cubic foot (3,250 kilograms to the cubic meter). Absorption by weight averages about 5 per cent and ranges from less than 4 to more than 7 per cent. Absorption by volume averages about 12 per cent and ranges from less than 9 to 15 per cent. Porosity by volume averages about 16 per cent and ranges from 13 to 20 per cent.

## QUARRYING METHODS AND PREPARATION

Although quarrying originally began at well-exposed ledges on cliffs, the selection of quarry sites has for several years depended upon core-drilling. After the site has been selected the overburden, if composed of residual soil, is removed by hydraulicking; if composed largely of the Mitchell limestone it is removed by blasting. The thickness of stone thus removed may reach 50 feet (15 meters) depending upon the amount and quality of the oolitic stone beneath it. A small part of this stone is sold as crushed stone and rubble, but the supply is much greater than the demand. At many places there is between the Mitchell limestone and the oolitic limestone a layer of soft shale from a few inches to a foot or more thick that protects the oolitic stone from the shock of blasting; at other places the two formations are in firm contact, and the depth of blasting must be limited by some higher layer of shale.

[2] Wessler, D. W., and Sligh, W. H., Physical properties of the principal commercial limestones for building construction in the United States: Bur. Standards Tech. Paper 349, 1927.

After removal of the overburden the oolitic stone is cut by channeling machines into long rectangular blocks. The longer dimensions of the blocks are commonly at right angles to the "mud seams," but if the "mud seams" are rather closely spaced and long blocks are desired the length of block must parallel the "mud seams." After removal of a "key block" to make room for workmen the base of a channeled block is loosened by wedging or "gadding," a sufficient quantity of spalls and dirt to serve as a cushion is spread beside the block, a cable from a derrick is attached to its edge, and it is then pulled over on its side. The block is then split into "mill blocks" by drilling rows of shallow holes with a jack-hammer drill and driving wedges into them. The mill blocks are commonly 8 to 12 feet (2.4 to 3.6 meters) long and 4 to 6 feet (1.2 to 1.8 meters) square, but blocks for monolithic columns may be 30 feet (9.1 meters) or more in length, and blocks of greater than ordinary width are prepared to meet special demands. "Short-length" blocks, less than 6 feet (1.8 meters) long or of irregular shape and not adapted for ordinary mill practice, are sold for range work and random ashlar. Mill blocks are sawed by gang saws into slabs that are most commonly 4 inches (10 centimeters) thick, although thinner and thicker slabs are sawed according to demand. The slabs are then cross sawed into rectangular blocks of desired size and finished according to specifications.

## COMMERCIAL GRADES

The stone is classified according to color and texture into the following grades:

### BUFF STONE

AA. Select buff statuary, of extra fine and uniform grain, especially adapted to carving.

A. Select buff (formerly "No. 1"), of generally fine and uniform grain, with a minimum of conspicuous "glass" spots or seams, shell holes, and other irregularities.

B. Standard buff (formerly "No. 2"), of less fine and uniform grain but not coarse grained; with only a few "glass" spots, shell holes, and other irregularities.

C. Rustic buff (formerly "coarse"), of irregular, prevailingly coarse grain, usually with conspicuous fossil shells, shell holes, or "glass" spots, and other irregularities.

### GRAY (FORMERLY "BLUE") STONE

D. Select gray (formerly "No. 1"); similar to A.

E. Standard gray (formerly "No. 2"); similar to B.

EE. Rustic gray; similar to C.

### VARIEGATED (BUFF AND GRAY) STONE

F. Variegated statuary; similar to AA.
G. Variegated (includes entire textural range of A, B, and C).

### SPECIAL GRADES

H. Special hard, buff; texture similar to that of A.
I. Special hard, gray; texture similar to that of A.
J. Old Gothic, unselected as to color and texture. Includes buff, gray, and variegated stone ranging from fine to very coarse but for the most part fairly coarse grained. Some pieces may have prominent shell holes, white or glassy streaks, tight crowfeet, and any other markings that exclude them from the other grades but do not affect soundness. This grade presents the widest variation in color and texture.
K. Short length, sawed strip stone produced from a mixture of short mill blocks less than 6 feet (1.8 meters) in length or of such irregular shape that rectangular slabs exceeding that length can not be obtained from them. Equal to the regular grades in chemical and physical properties, and well adapted for range work and random ashlar.

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# THE FLUORSPAR DEPOSITS OF SOUTHERN ILLINOIS

By Edson S. Bastin

ABSTRACT

The fluorspar deposits of southern Illinois occur in a region of dominantly sedimentary rocks which have been broadly arched to form the Hicks dome and which are displaced by many faults of prevailing northeast trend. The formations range in age from Devonian to Pennsylvanian, but most of the fluorspar mines are in Mississippian rocks (Chester group). The deposits are of two types—(1) steeply inclined replacement veins following the faults, (2) flat-lying or "blanket" deposits restricted to certain limestone beds and characterized by diffusion banding. The veins are typically developed near Rosiclare, and the blanket deposits near Cave in Rock. The evidences of origin by replacement are fully presented.

Fluorite and calcite are the dominant minerals of the veins; galena, sphalerite, chalcopyrite, and pyrite occur as accessories. The same minerals characterize the blanket deposits except that calcite is subordinate and sulphides are rare. Quartz is rare in both types. Barite is always secondary.

The presence of peridotite dikes suggests that the mineralizing solutions rose from buried magmatic sources.

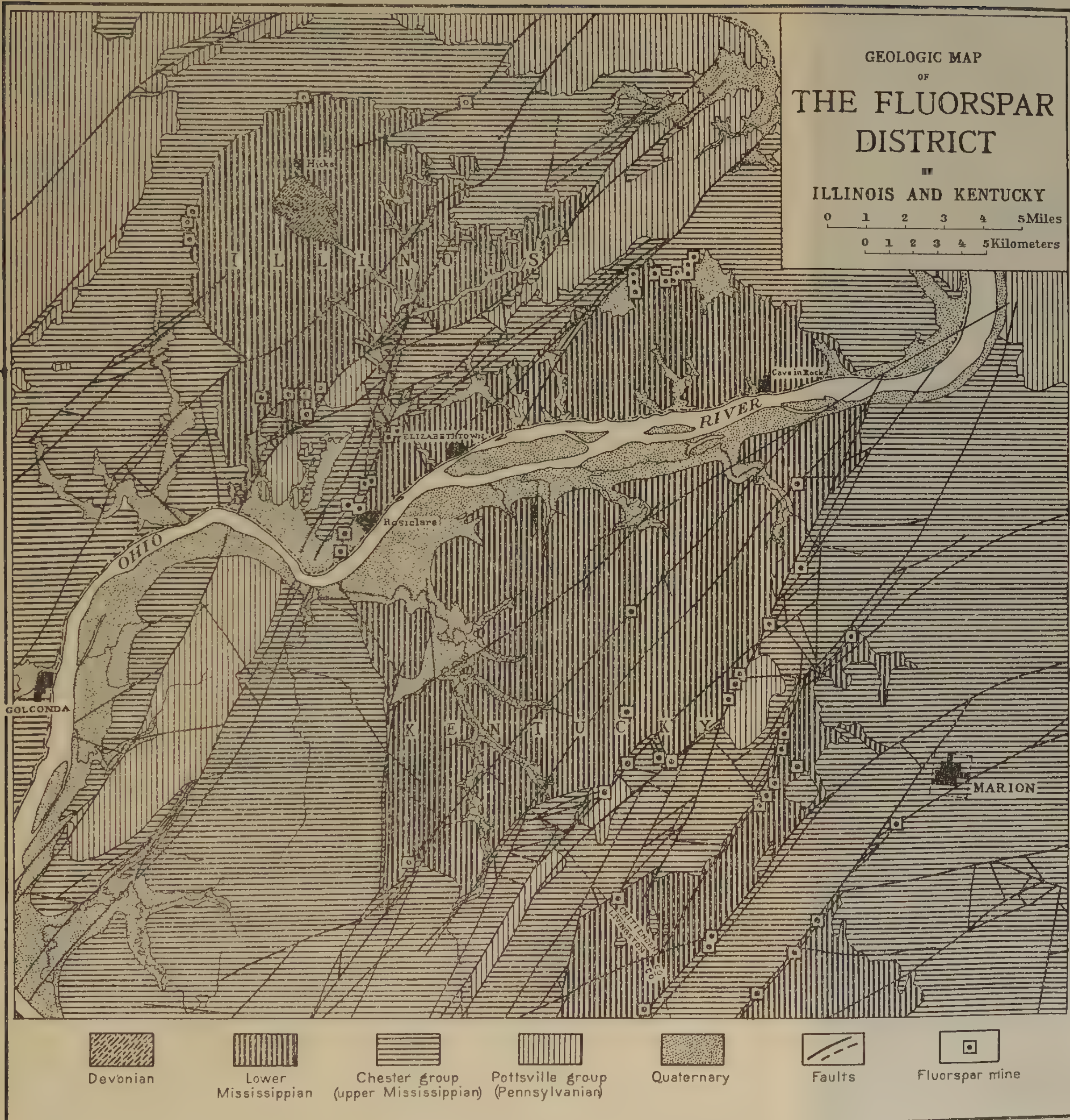
## HISTORY AND PRODUCTION

The Illinois-Kentucky fluorspar district, whose approximate extent is shown in Plate 3, is the world's principal producing district.

Though the occurrence of fluorite was recognized over 100 years ago, galena was the object of all the early prospecting and mining, the associated fluorite being neglected. It was not until about 1900 that fluorspar mining assumed notable proportions. The early operations in Illinois centered about Rosiclare, and until 1919, when the railroad was extended to Rosiclare, all fluorspar was shipped from that district by boat. Shipments from Cave in Rock are made by barge, and recently, with the improved facilities for barge navigation on the Ohio River, river shipments from Rosiclare have been resumed. The production of the district is shown in Figure 8.

## GENERAL GEOLOGY

The district is occupied mainly by Mississippian and Pennsylvanian sediments, but a small area of Devonian rocks occurs in the Hicks dome (pl. 3).




Compiled from original sources by Hakon A. Waddell.

*Generalized columnar section in fluorspar district of Illinois*

[After Stuart Weller]

| System | Group | Formation | Approximate thickness: Feet | Approximate thickness: Meters |
|---|---|---|---|---|
| Pennsylvanian. | Pottsville. | Tradewater. | 300 | 91 |
| Mississippian. | Upper Chester. | Caseyville conglomerate. | $2\frac{1}{8}$–400 | 0.65–122 |
| | | —Unconformity— | | |
| | | Kinkaid limestone.<br>Degonia sandstone.<br>Clore limestone. | 150–200 | 46–61 |
| | | Palestine sandstone. | 60 | 18 |
| | | —Unconformity— | | |
| | | Menard limestone. | 80–120 | 24–37 |
| | | Tar Springs sandstone. | 100–150 | 30–46 |
| | | —Unconformity?— | | |
| | Middle Chester. | Glen Dean limestone. | 50–70 | 15–21 |
| | | Hardinsburg sandstone. | 30–100 | 9–30 |
| | | —Unconformity— | | |
| | | Golconda formation. | 150 | 46 |
| | | Cypress sandstone. | 80–100 | 24–30 |
| | | —Unconformity?— | | |
| | Lower Chester. | Paint Creek formation. | 40–50 | 12–15 |
| | | —Unconformity?— | | |
| | | Bethel sandstone. | 50–100 | 15–30 |
| | | —Unconformity— | | |
| | | Renault limestone. | 50 | 15 |
| | | —Unconformity?— | | |
| | | Shetlerville formation. | 30 | 9 |
| | | —Unconformity— | | |
| | Meramec. | St. Genevieve limestone. | 150–200 | 46–61 |
| | | St. Louis limestone. | 350 | 107 |
| | | Warsaw limestone. | 250 | 76 |
| | Osage. | Osage formation. | 550 | 168 |
| Devonian. | Upper Devonian. | Chattanooga shale. | 400 | 122 |
| | Middle Devonian. | Devonian limestone (base not exposed). | 200 | 61 |

Fluorspar deposits are found in all these formations, but the wall rocks at most of the mines are Mississippian, of the Meramec and Chester groups.

The arching of the Hicks dome (pl. 3) was accompanied and perhaps in part caused by igneous intrusions. The intrusive rocks appear at the surface only as scattered peridotite dikes, with prevailingly northwesterly trends and steep dips, but the dikes may be offshoots from larger intrusive masses below. They have been found as far north as Harrisburg, Illinois, and as far south as Princeton, Kentucky, and they range from a foot (0.3 meter) or less to over 100 feet (30 meters) in width.

After the folding normal faulting followed on a large scale. The major faults trend northeast and displace not only the folded beds but, in some places, the peridotite dikes.

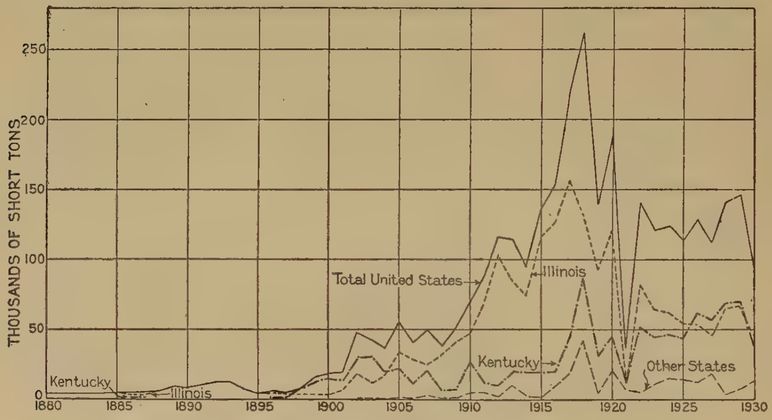



FIGURE 8.—Production of fluorspar in the United States, 1880–1930

Then followed mineralization, principally along some of the faults, forming vein deposits, but subordinately following the bedding of limestones and forming "blanket" deposits. The products of the mineralization were mainly fluorite and calcite, but with these were deposited galena and sphalerite, and in a few deposits the sulphides predominate.

The uplift occurred, in large part at least, after mid-Pennsylvanian time, for rocks of this age were involved in the arching. The folding, as well as the igneous activity and the mineralization, was completed before Cretaceous time, for flat-lying and unmineralized rocks of Cretaceous age overlie the folded and faulted beds in Kentucky.

How long an interval was represented by the sequence of folding, igneous intrusion, faulting, and mineralization is stil

uncertain, but most geologists who have studied the region believe that the mineralization followed close upon the heels of the igneous intrusions and was accomplished by solutions coming from the same deep-seated magmatic sources.

## TYPES OF FLUORSPAR DEPOSITS

The fluorspar deposits of Illinois may be classed as veins and blanket deposits. The vein deposits, typically developed near Rosiclare (see fig. 9), have been the source of the larger part of the fluorspar produced in Illinois as well as in Kentucky.

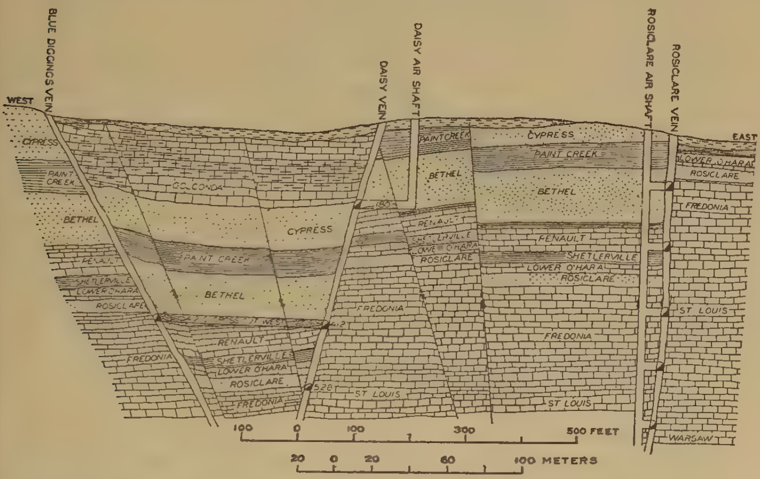



FIGURE 9.—Diagrammatic cross section showing stratigraphic and structural relations in the vicinity of Rosiclare, Illinois

They are steeply inclined sheetlike deposits that cut across the nearly flat-lying sedimentary beds of the region, against which they have prevailingly sharp contacts. It is clear that they were deposited along fault planes and fracture zones. The blanket deposits, of which those at Spar Mountain and Lead Hill, near Cave in Rock, are typical, are flat-lying and follow in a general way the bedding of the sediments in which they occur. They have been formed through the replacement of limestone by fluorite and associated minerals.

### VEIN DEPOSITS

*Distribution.*—The bulk of the fluorspar produced in Illinois formerly came from a single large vein, the Fairview-Rosiclare, near the town of Rosiclare; but since 1924, when the workings

in that vein were flooded, the Hillside and Daisy mines have been the principal producers. Fluorite veins as far as 10 miles (16 kilometers) north of Rosiclare have been worked, but production from these outlying veins has been relatively insignificant.

*Mechanism of vein formation.*—The fluorspar veins cut indiscriminately sandstone, shale, and limestone beds. Against all of these the contacts are prevailingly sharp, so that the veins have the general appearance of fissure fillings and have been so interpreted by most of the geologists who have studied them.

However, there is unmistakable evidence that replacement has played an important part in their formation. The evidence of replacement consists in (1) the preservation in the ores of stylolitic partings and associated limestone remnants, (2) the preservation in the ores of ragged limestone remnants that clearly could not have resulted solely from fracturing, and (3) the local presence of multiple or rhythmic banding in the ores.

In several localities in Kentucky stylolitic partings were traced without a break or deflection from limestone into vein material. An early stage in the replacement of limestone by calcite and fluorite along a stylolitic parting is shown in Plate 4, *A*. A more advanced stage of mineralization in which only minor remnants of limestone remain in a mass of calcite and fluorite is illustrated in Plate 4, *B*. The persistence of some of the stylolitic partings across the whole specimen indicates that before replacement the limestone was not a jumble of diversely oriented fragments, although it was doubtless somewhat fractured.

Limestone fragments are common in many of the veins. Though many of these are angular, others are extremely ragged and irregular in outline, indicating that the limestone country rock has been partly replaced by vein minerals. Different types of limestone clearly differed in their susceptibility to replacement, for many fragments of dense, fine-grained limestone are angular, whereas fragments of coarser limestone are exceedingly ragged.

Rhythmic banding was observed in the wall of the Hillside vein at Rosiclare (170-foot (52-meter) level) where 40 bands occur in a width of 6 inches (15 centimeters), and in places there are as many as 12 bands to the inch. The lighter bands are fluorite, and the darker bands are a mixture of fluorite, quartz, ferruginous calcite, and galena. Banding of the sort just described is regarded as the result of rhythmic deposition of mineral matter during replacement.

*Mineralogy of the veins.*—The following minerals have been noted in the veins:

| Primary vein minerals: | Secondary vein minerals: |
| --- | --- |
| Fluorite, Calcite (dominant). | Barite. |
| Ferruginous calcite. | Gypsum. |
| Quartz (minor). | Malachite. |
| Galena. | Cuprite. |
| Sphalerite. | Many others. |
| Pyrite. | Miscellaneous: |
| Chalcopyrite. | Oil and bitumen. |

Fluorite is the principal mineral of economic value in the vein deposits and ranks next to calcite in abundance.

Quartz is a very minor primary mineral in the fluorite veins and was commonly deposited late in the mineralization, usually as small crystals in vugs.

Galena is the most common sulphide in most of the veins. In the main it crystallized later than most of the calcite and fluorite, for it occurs in veinlets traversing these minerals, particularly the fluorite. The galena veinlets are primary and were formed by replacement along zones of minor fracturing.

Sphalerite is not as widespread in the veins as galena but is abundant in some places. It occurs in the veins and also to a minor degree as a replacement product of the wall rock. It appears to be about contemporaneous with most of the fluorite. Alternate diffusion bands of fluorite and sphalerite indicate essentially contemporaneous deposition of the two minerals.

Pyrite is rather widespread in the fluorite veins but is in general quantitatively subordinate. Some pyrite clearly crystallized before the deposition of fluorite was completed, but where pyrite is most abundant it appears to have been deposited after the fluorite mineralization—perhaps long after.

Chalcopyrite is a minor but fairly common component of the veins. No attempt is made to recover it in the fluorspar milling.

Barite was not noted in any of the ores from the deeper portions of the veins. All available evidence indicates that, like most of the pyrite, it was deposited after the deposition of fluorite had ceased—perhaps long after. Its greater abundance near the surface suggests that it was deposited from cool ground waters.

*Relations between calcite and fluorite.*—The mutual relations of the two principal vein minerals, calcite and fluorite, are significant in their bearing upon the origin of the ores. In general calcite is more abundant nearer the walls and fluorite more abundant nearer the central portion of the veins; calcite tends to become more abundant and fluorite less abundant where the veins fork and pinch and show signs of playing out.

In some places calcite and fluorite are intimately intercrystallized. Relations of this sort are found on the 350-foot (107-meter) level of the Hillside mine, where crystals of calcite as much as 3 inches (7 centimeters) across lie in a matrix of white fluorite. The contacts between the two minerals are prevailingly straight, clean-cut crystal faces of calcite, clearly demonstrating that fluorite has not replaced calcite. Calcite appears to have crystallized first and fluorite to have formed around it. In other places in the same mine, however, irregular mixtures of calcite and fluorite of the sort just described are traversed by ramifying networks of younger fluorite veinlets. Finally, there are microscopic indications that fluorite has locally replaced calcite with the development of its own characteristic cubical outlines.

It would appear that in the early stages of mineralization vein calcite was deposited more abundantly than fluorite; then fracturing took place within the vein, and along the fractures more fluorite was deposited, partly by filling and partly by replacement.

*Oil and bitumen in the veins*.—Petroleum occurs here and there in the fluorspar veins near Rosiclare. An irregular dark stain near the center of the Daisy vein is due to oil that seeped out from an open part of the vein. The oil is light brown, viscous, and sticky and burns readily, with a luminous, smoky flame. Some of it was sufficiently fluid to drip from the roof of the drift. Minute inclusions of brown oil have been found within colorless fluorite. Thin coatings of black bitumen also occur on the minerals in small vugs.

In general, these relations indicate that petroleum was present in a few places in some of the fluorite veins before the crystallization of fluorite ceased. They further indicate that it evaporated from some of the vugs, leaving only a bituminous residue. The fact that oil is not present in all veins or in all parts of the same vein suggests that it was derived locally from sediments traversed by the mineralizing solutions.

*Vugs*.—Vugs, or cavities formed when the veins were deposited, are only moderately numerous. The largest ones noted, 2 by 3 feet (0.6 by 0.9 meter) and 3 by 5 feet (0.9 by 1.5 meters) on the 350-foot (107-meter) level south, Hillside mine, occurred in calcitic portions of the vein and were lined solely with scalenohedral crystals of calcite. Vugs in highly fluoritic portions of the vein are smaller and are commonly lined with crystals of fluorite. The choicest crystals of transparent fluorite are said to be pendant from the roofs of the vugs.

*Two generations of fluorite.*—Small amounts of fluorite are clearly somewhat younger than the main fluorite deposits. This younger fluorite is of considerable genetic significance.

In a specimen from the Hillside mine some of the faces of cubical crystals of white fluorite are coated with white calcite crystals with which are intergrown small crystals of pyrite and a few small crystals of purple fluorite. In another specimen small crystals of chalcopyrite are inclosed within or indent or coat the faces of cubical crystals of clear, transparent fluorite. These in turn are coated with a layer of calcite crystals, and on this pyrite and fluorite have been deposited.

## BLANKET DEPOSITS

With the increasing difficulties encountered in Illinois in working the vein deposits, owing to exhaustion and flooding, attention has been directed toward a more thorough exploration of the blanket deposits. They have the natural advantage of being flat-lying, so that they can be worked by open pits or shallow underground workings with simple mining methods and with natural drainage for the mines. Preparation for the market is relatively simple, for in contrast to the vein deposits the blanket deposits contain little calcite and galena and do not require elaborate treatment. Furthermore, very little waste material need be excavated in mining; over a period of 2½ years in the recent operation of the Spar Mountain replacement deposits the shipped product constituted 91.7 per cent of the crude ore mined. It is estimated that the final product constitutes 85 to 90 per cent of the crude ore of the blanket deposits, as contrasted with 40 to 60 per cent for the vein deposits. The principal blanket deposits of fluorspar are located at Lead Hill and Spar Mountain, about 4 miles (6.4 kilometers) northwest of Cave in Rock and about 10 miles (16 kilometers) northeast of Rosiclare. Where the blanket deposits near Cave in Rock are close to the surface they are worked by open-pit methods, but underground methods predominate and closely resemble those used in working the "sheet ground" of the Joplin zinc district, Missouri.

*Occurrence.*—The blanket deposits occur in the Ste. Genevieve formation, which beginning at the base includes the Fredonia oolitic limestone, the Rosiclare sandstone, and the Ohara limestone. The Rosiclare sandstone contains at the top a few inches to a few feet of greenish shale.

The deposits are prevailingly banded in the fashion shown in Plate 5, *B*. The ores are commonly bounded above by shale, which may be succeeded directly below by banded ore, or a zone

of coarsely massive ore as much as 2 feet (0.6 meter) thick may intervene. It is in the coarsely massive ores that the largest and finest crystals of fluorite are found. Some of the best exposures of the banded ores occur near the portal of the main or lower tunnel of the Cave in Rock mine, where the mineralized zone is at least 8 feet (2.4 meters) thick and in general parallels the bedding of the associated sandstone, shale, and limestone. The ore here consists of bands of coarse fluorite as much as 1½ feet (0.45 meter) wide alternating with ore that is finely banded. (See pl. 5, *A*.)

As a rule the banding is nearly parallel to the bedding planes of the inclosing rocks, but there are marked departures from parallelism. In a few places in the Spar Mountain workings the banding is V-shaped or W-shaped in cross section (fig. 10) where it follows narrow fractures that continue in the shale and sandstone roof. The divergences demonstrate that the banding is not an inheritance from either bedding or cross-bedding of the sediments.

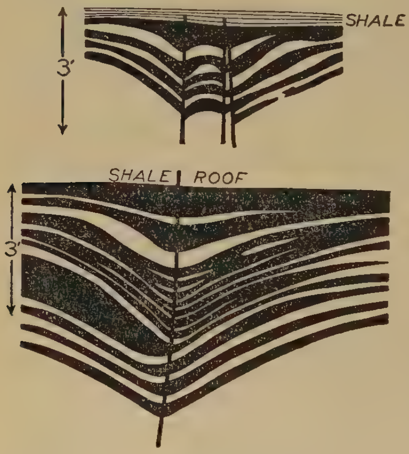
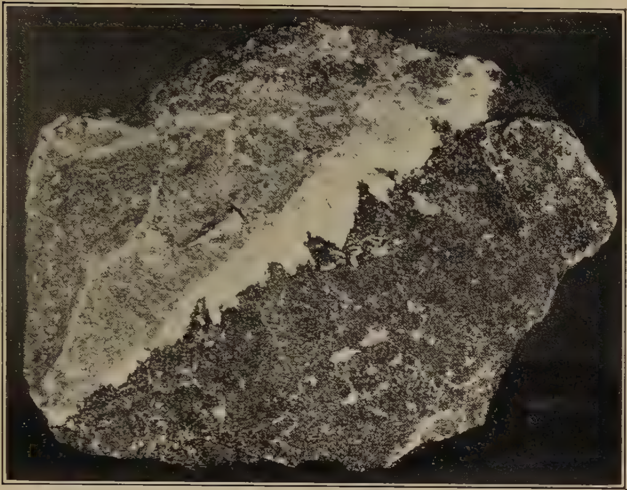



FIGURE 10.—V-shaped diffusion banding along small fissures

Vugs are common in the coarse ores just below the shale cap. Most of them are largest in horizontal dimensions. One vug 6 inches (15 centimeters) high was 4 feet (1.2 meters) across; another 2 feet (0.6 meter) high was 5 feet (1.5 meters) across. Vugs in the banded ores are small.

The mineralization in general follows the bedding of the Mississippian strata. The deposits lie east of the Rosiclare area of severe faulting, and gentle arching is the controlling structural feature. Although faults of notable displacement are rare, minor fractures showing little or no displacement have exerted an important influence in guiding the mineralizing solutions and have been found to be useful "leaders" in following the ore, because near them the ore is likely to be unusually thick and of high grade.

The deposits occur in the limestones and are notably absent from the associated sandstones and shale, except that small



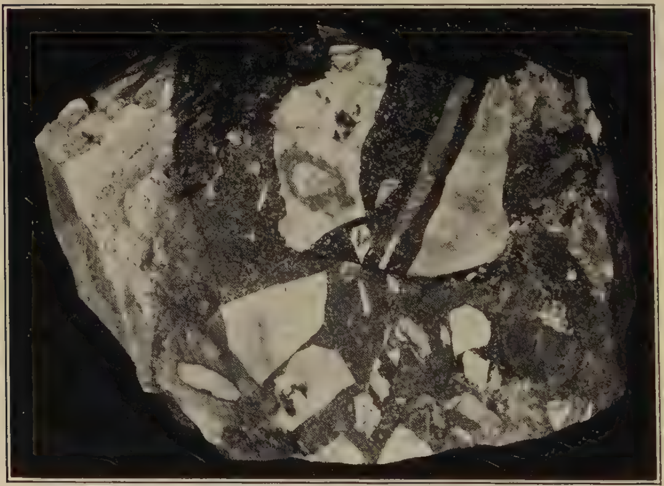
*A.* A STYLOLITIC PARTING SEPARATING A LIGHT-COLORED BAND OF CALCITE AND FLUORITE FROM LIMESTONE

About half natural size.

*B.* NEARLY COMPLETE REPLACEMENT OF STYLOLITIC LIMESTONE BY VEIN CALCITE AND FLUORITE

*A*. DIFFUSION BANDING IN FLUORITIC MATERIAL

The bands of fluorite (white) are one-half to three-fourths inch wide. (After Bain.)



*B*. JASPEROID ORE BRECCIA FROM GRACE WALKER MINE, PICHER

Fragments of white chert in matrix of dark chert, sphalerite, dolomite, etc. About half natural size. (From Oklahoma Geol. Survey Bull. 56, 1932. See p. 78.)

fractures in the shale have been filled by fluorite. The base of the Rosiclare sandstone and shale marks the upper limit of notable mineralization. The ores are associated principally with the coarser limestones, which are commonly oolitic, and the darker-gray, denser, nonoolitic limestones are mineralized only in a few places.

Although the maximum mineralization occurred nearest the shale capping, ore may extend with interruptions as far as 30 feet (9 meters) below the capping. For example, in one place banded ore not only immediately underlies the capping shale but also occurs 20 feet (6 meters) below the shale, beneath a bed of fine-grained, nonoolitic limestone. At another place three distinct zones of banded ore are separated by beds of dense, nonoolitic limestone.

*Origin.*—Replacement has been the dominant mechanism of ore deposition. The replacing solutions were guided mainly by minor fractures and by bedding planes, and the filling of openings was a negligible factor. The outstanding features of the blanket deposits are (1) the absence of fracturing on a large scale, (2) the preservation in the ores of features characteristic of the limestone, (3) the prevailing absence of important mineralization in sandstone and shale and its prevalence in more soluble limestone, (4) the obvious influence of narrow fractures in determining the form and distribution of wide ore bodies, and (5) the common development of a peculiar type of banded ore which implies rhythmic deposition by replacement.

Structural features originally in the limestones and preserved in the fluorite ores include fossils, stylolitic structure, oolitic structure, and the forms of calcite crystals. Well-preserved fossil echinoderms (blastoids), some of which have been replaced by both quartz and fluorite, have been found in residual soils derived from banded fluorite ore and limestone. Some of the delicate ambulacral plates are now wholly fluorite.

The peculiar banded structure shown in the fluorite of Lead Hill and Spar Mountain can have been produced apparently only by replacement. The restriction of fluorite ore to the soluble limestone is in itself evidence of replacement of the limestone by fluorite.

*Mineralogy of the blanket deposits.*—In the blanket deposits the layers in the banded material are of two sorts: (1) Coarse-grained bands one-fourth to three-fourths of an inch (0.6 to 1.9 centimeters) wide are composed wholly of colorless to gray or purplish fluorite in crystals that may reach half an inch (1.2 centimeters) across. At some places small cavities in the centers of the bands are lined with small fluorite crystals and

contain some colorless to smoky quartz. (2) Alternating with the coarser bands are fine-grained bands one-half to three-fourths of an inch (1.2 to 1.9 centimeters) wide which are composed mainly of gray to pale-purplish fluorite with minor amounts of finely crystalline quartz.

Grab samples of the banded ores from the Lead mine and the Cleveland mine at Spar Mountain show from 92 to 94 per cent of calcium fluoride. Much of the banded ore if cleanly mined requires no concentration.

Replacement was less complete as the mineralizing solutions penetrated farther into the limestone. This is illustrated in the Green mine, where banded ore nearest the shale capping is of high grade, whereas banded ore farther below the capping is notably calcareous, its finer bands effervescing freely with dilute acid. The minerals of the coarser nonbanded blanket ores are the same as those of the vein deposits, but their proportions are significantly different. They include the following:

| Primary: | Secondary: | Miscellaneous: |
|---|---|---|
| Fluorite. | Barite. | Petroleum. |
| Calcite. | Fluorite. | Bitumen. |
| Galena. | Smithsonite. | |
| Sphalerite. | | |
| Quartz. | | |
| Chalcopyrite. | | |
| Marcasite. | | |

In the veins calcite is the dominant mineral, but in the blanket deposits it is absent from the banded ore except as remnants of limestone and is very subordinate in the coarse nonbanded ore.

Of the other minerals, barite is of subordinate commercial importance. It is saved in mining, and shipments are made when considerable amounts have been accumulated. Galena is very subordinate, and no attempt is made to recover it. Sphalerite is inconsequential in quantity.

Fluorite is the dominant mineral of all the blanket deposits. The largest and most nearly perfect crystals are developed in the vugs that usually occur in the coarser ore just below the shale capping. Individual fluorite crystals as large as 7 inches (18 centimeters) across occur, but usually they are less than 3 inches (8 centimeters) in diameter. The fluorite may be colorless or light gray, pale greenish blue, light amber, pale purple, or deep purple. It varies from transparent to translucent, the petroleum-bearing varieties being especially likely to be clouded and translucent. Small amounts of colorless fluorite clear enough to be suitable for optical uses form the centers of some crystals.

Nearly all of the fluorite clearly belongs to a single period of primary mineralization, but during a later period fluorite was

deposited in a few places in amounts too small to be commercially important. Etching and pitting of coarse fluorite by the solvent action of ground water was noted in several places, and locally this etching was followed by the deposition of coatings of secondary calcite, barite, and fluorite.

In the finely banded ores calcite forms only minute grains and seems to be a recrystallized remnant of incomplete replacement. Coarsely crystalline calcite is abundant at some places in vugs in the coarser nonbanded ores. Crystallization of primary calcite seems to have begun late in the period of primary mineralization, before crystallization of fluorite had ceased, and persisted longer than the fluorite deposition.

Barite is significantly absent from most of the fluorite ore in the blanket deposits. It appears to be a secondary mineral formed after the deposition of the primary fluorite—perhaps long after—but contemporaneously with some secondary fluorite. It either coats or replaces primary calcite and fluorite or replaces sandy limestone and is restricted to deposits near the surface. Its occurrence is well illustrated in the Cleveland workings, where, owing to the slope of the hillside, the horizontal drifts approach and finally reach the surface as they extend northward. As the surface is approached barite appears in vugs in the coarse ore and is most abundant nearest the surface. At some places it forms pendants or blunt stalactites hanging from the fluorite crystals in the vugs. Some of the pendants are stained brown superficially by limonite, and on the brown-stained surfaces small tufts of white barite crystals of a second generation have been deposited, showing clearly that barite was deposited not only later than the primary fluorite but also after the deposit had been somewhat oxidized and iron stained.

Quartz is rare in the blanket deposits and is probably secondary. Chalcopyrite and marcasite occur as inclusions within cubical crystals of fluorite.

Oil inclusions are fairly common in the coarser fluorite ores of Spar Mountain, which formed mainly during the late stages of the primary mineralization. They follow crystallographic planes in the fluorite. When freshly broken or when drilled with compressed-air drills, much of the ore yields a distinct petroleum odor. Although more noticeable in the coarsely crystalline ore, petroleum is present also in the banded ore.

## GENESIS OF THE FLUORSPAR DEPOSITS

The replacement of limestone on a scale such as is observed in both blanket and vein deposits implies an intimate penetration of the limestone by the mineralizing solutions; this is notably true where stylolitic and oolitic structures have been preserved in minute detail in material now wholly fluorite. Such intimate penetration seems to imply highly mobile mineralizing solutions.

The temperature of the mineralizing solutions was probably moderate. No minerals diagnostic of high-temperature conditions are present either in the veins or in the blanket deposits. The inclusions of amber-colored liquid petroleum in fluorite during the late stages of primary mineralization indicates that the temperature was probably below 300° C.

No new evidence bearing upon the source of the mineralizing solutions was acquired in the course of this investigation. Bain, Fohs, Weller, and Currier have all regarded them as emanations from deep-lying bodies of igneous rocks whose presence is indicated by scattered dikes. The proximity of a large igneous intrusion is also suggested by a slight doming of the strata and the complex pattern of mosaic block faulting.

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# THE DISSEMINATED-LEAD DISTRICT OF SOUTHEASTERN MISSOURI

By H. A. Buehler

ABSTRACT

The disseminated lead district of southeastern Missouri is the largest lead-producing district in the United States. It lies 60 miles south of St. Louis, at the eastern margin of the Ozark uplift. (See pl. 6.)

The ores occur in the Upper Cambrian Bonneterre dolomite and to a minor extent in the upper part of the underlying Lamotte sandstone. The ore bodies are large flat, tabular masses in which galena occurs mainly in disseminated form. Ore also occurs as horizontal sheets along bedding planes, filling small cavities, and lining walls of fractures or joints. Other ore and gangue minerals occur sparingly. The ore bodies generally follow systems of joints.

Though workable ore bodies have been developed over a large area, embracing parts of several counties, the most productive portion of the district is confined to an area 9 by 7 miles (14 by 11 kilometers) in St. Francois County.

The average grade of the ore is 3 to 4 per cent lead, and it is now treated in seven mills that have been brought under the ownership of two large companies.

## HISTORY AND PRODUCTION

The first explorers in what is now the Ozark region of southeastern Missouri discovered and mined lead ores as early as 1725, and, except for interruptions during the early years, the district has advanced in importance until to-day it has a larger yearly production than any other lead district in the world. Prior to 1869 practically all the lead was obtained from shallow workings, the ore occurring as large masses in crevices, solution channels, caves, and other mud-filled openings. The introduction of the diamond drill in that year proved the most important step in the development of the district, as drilling showed the existence of ore of the disseminated type at greater depth. Because of the low grade of the ore, the district is one of large scale operations. Under normal operating conditions approximately 25,000 tons (22,680 metric tons) of ore is mined daily. The mines have gradually been consolidated under the ownership of two operating companies—the St. Joseph Lead Co. and the St. Louis Smelting & Refining Works of the National Lead Co. The following table shows, in 10-year periods, the production of the district since 1869. This production came almost exclusively from the disseminated type of deposits, although the output of the shallow workings of the Washington County area is included.

*Quantity and value of lead concentrates produced in southeastern Missouri, 1869–1930*

| | Tons | Metric tons | Value |
|---|---|---|---|
| 1869–1880 | 25, 497 | 23, 130 | $2, 295, 509 |
| 1881–1890 | 173, 735 | 157, 610 | 9, 239, 604 |
| 1891–1900 | 759, 337 | 688, 858 | 14, 623, 024 |
| 1901–1910 | 980, 190 | 889, 214 | 48, 764, 566 |
| 1911–1920 | 2, 541, 667 | 2, 305, 760 | 154, 897, 013 |
| 1921–1930 | 2, 749, 560 | 2, 494, 359 | 214, 016, 591 |
| | 7, 229, 986 | 6, 558, 931 | 443, 836, 307 |

## TOPOGRAPHY

The Ozark Plateau, which embraces the southern half of Missouri and the northern portion of Arkansas, is a dome-shaped uplift, rugged and hilly but not mountainous. Over much of the area the uplands have an average altitude of 1,000 to 1,600 feet (305 to 488 meters); the highest points do not exceed 1,800 feet (549 meters). The drainage level ranges from 600 to 900 feet (183 to 274 meters). The greatest topographic relief and most scenic portion of the Ozarks is embraced in the area of outcrop of the igneous rocks throughout the St. Francois Mountains, near the eastern border of the uplift. The disseminated lead district includes a part of this area and extends beyond it to the north into St. Francois County, where the relief is much less, the surface being somewhat hilly to rolling and in part a fair farming country. The productive portion of the district is devoid of rugged topographic features such as characterize many of the western mining camps.

## GEOLOGY

The uplift that formed the Ozark Plateau brought to the surface a succession of Ordovician, Cambrian, and pre-Cambrian rocks, which in the surrounding region are buried beneath younger strata.

### IGNEOUS ROCKS

The entire Ozark region is underlain by igneous rocks, chiefly granite and porphyry, which are undoubtedly of pre-Cambrian age. Although no positive correlation with the pre-Cambrian in other parts of the continent has been made, they are thought to be of Algonkian age. These igneous rocks crop out only in the southeastern part of the State, in Madison, St. Francois, Iron, and adjoining counties. (See fig. 11.)

Both the porphyry and the granite are cut here and there by basic dikes, usually of rather slight extent. The exact age of these dikes is not known, although in part at least they are later than Upper Cambrian, as they intrude the Bonneterre dolomite

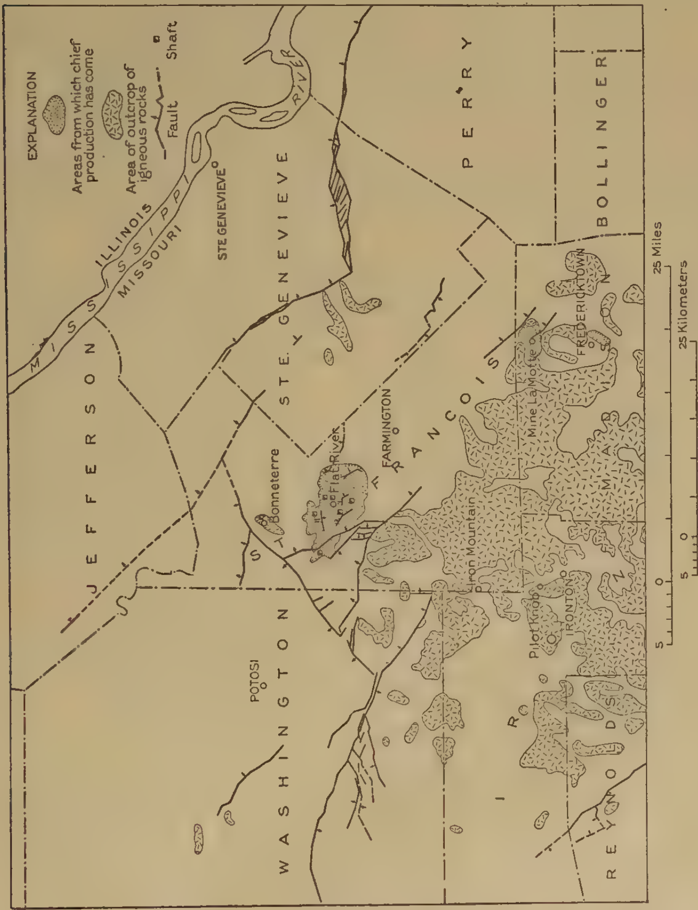



FIGURE 11.—Map of southeastern Missouri showing faults and productive areas

in Ste. Genevieve County. Within the productive area diamond drills have occasionally encountered basic rocks at the contact of the sediments with the underlying igneous rocks, but nowhere is there any evidence of intrusion of the basic rocks into the overlying beds.

## SEDIMENTARY ROCKS

During Lower and Middle Cambrian time the area was a part of the continental mass, and the surface was carved to a rugged topography, with a relief even greater than that of the present time.

*Lamotte sandstone.*—The oldest sedimentary formations are of Upper Cambrian age. The first evidence of sedimentation is usually a conglomerate, made up largely of detrital material derived from the weathering igneous rocks. This conglomerate grades upward into a coarse to fine grained sandstone, the Lamotte, which varies greatly in thickness but reaches more than 200 feet (61 meters) in the old pre-Cambrian valleys. Where the basement rocks projected above the sea the sandstone is absent.

*Bonneterre dolomite.*—With the gradual sinking of the terrain the Bonneterre formation was deposited. It consists of a series of dolomitic beds having a total thickness of 300 to 400 feet (91 to 122 meters). In this formation occur the disseminated lead deposits.

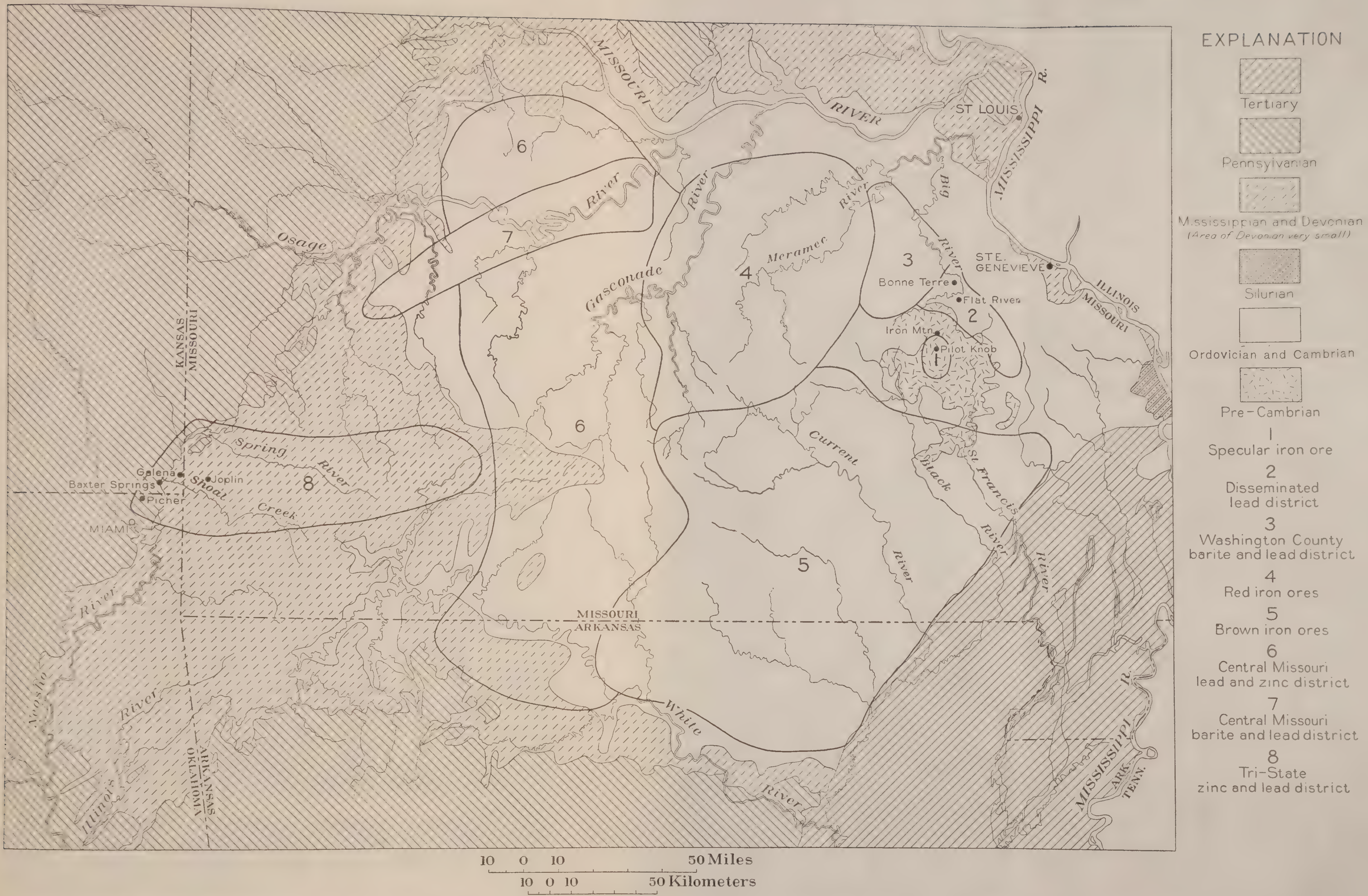
The upper portion of the formation usually consists of light-gray crystalline dolomite. The middle and lower portions are far more shaly, with beds of calcareous shale interstratified with the dolomite. The lower strata are darker and contain more organic material than the upper ones. In general, the bottom of the formation is glauconitic, the glauconite in some places almost completely replacing the arenaceous dolomite. The formation is noncherty.

The ore bodies occur in the lower beds containing much organic material and are not found in the upper light-colored rock. Organic material seems to follow broad, sloughlike areas that apparently favored the growth of abundant vegetation.

The Bonneterre formation crops out over much of the productive area.

*Davis shale.*—Overlying the Bonneterre is the Davis shale, which has a thickness of about 160 feet (49 meters). This formation carries no ore. It consists of rather thin-bedded calcareous sandy dolomite, interbedded with bluish shale, and the contact with the Bonneterre is usually marked by a very fine grained calcareous sandstone. Several beds of edgewise conglomerate consisting of thin, platy dolomite, cemented by sandy detrital material, occur in the lower part of the Davis, beneath a 3 to 5 foot (0.9 to 1.5 meter) bed of pure fine-grained limestone known as the "boulder bed."

*Derby and Doerun dolomites.*—The Derby and Doerun dolomites, with a combined thickness of about 150 feet (46 meters), overlie the Davis and are the remaining Cambrian formations.




GEOLOGIC MAP OF PARTS OF MISSOURI, OKLAHOMA, AND KANSAS SHOWING DISTRIBUTION OF DIFFERENT TYPES OF ORE DEPOSITS

The Derby consists of thick dark-gray noncherty dolomite; the Doerun of buff argillaceous dolomite. No ore is found in these formations.

*Potosi formation.*—The Potosi, a cherty dark-gray crystalline thick-bedded dolomitic formation of Upper Cambrian age, comprises the initial deposits of the Ozarkian of Ulrich. It has an average thickness of 400 feet (122 meters). The Potosi crops out at few places within the productive area, its presence being determined usually by the occurrence, in the residual soil, of typical Potosi chert known as "mineral blossom." When this district was first mapped geologically, the overlying thick beds of light-colored dolomite now known as the Eminence were included in the Potosi.

Within the disseminated lead district the formations above the Bonneterre usually cap the ridges and higher parts of the area and are devoid of mineralization.

To the north and west of the district, in Washington and Jefferson Counties, notable concentrations of barite and galena are found in the residual clays and in solution channels along fracture planes in the Potosi and Eminence formations. The Washington County area is the largest barite-producing district in the United States. Important centers of production have been Potosi, Mineral Point, and Old Mines. Though it is less than 25 miles (40 kilometers) from the lead district, the character of mineralization in the two districts is very different, and the ores occur at different geologic horizons. There is no barite associated with the galena of the disseminated lead district, whereas in the Washington County area barite is the major mineral, and the associated galena is of large crystal habit.

*Formations outside the productive area.*—The formations above described are those found within the productive area. To the east, north, and west the succession is overlain by later Ordovician formations consisting, in ascending order, of the Van Buren and Gasconade dolomites, the Roubidoux sandstone, and the Jefferson City, Cotter, and Powell dolomites. These formations underlie the major portion of southern Missouri and northern Arkansas, and small quantities of lead, zinc, and copper have been mined near the surface over much of the area they occupy. Throughout the central part of this area, the so-called "filled sink" district, there are widespread surface deposits of red and specular iron ore. None of these upper formations carry disseminated lead ore.

The stratigraphic succession, therefore, consists of pre-Cambrian granites and porphyries, overlain by normal sandstones, dolomites, and shales which do not show any material alteration or metamorphism.

## STRUCTURE

The district is one of essentially flat-lying sedimentary rocks, which show no pronounced folds or steep inclination of beds.

There is a gentle dip westward from Farmington, where the Lamotte sandstone crops out, to a point west of Irondale, where the top of the sandstone is more than 600 feet (183 meters) beneath the surface. No well-defined system of folds has been outlined, but drilling has indicated a variation in the position of the contact between the Lamotte and Bonneterre formations. Recent field work with the magnetometer has shown that where this contact is high it overlies a relatively high area of the underlying igneous rocks, and that the gentle dips away from this high area are probably initial dips due to sedimentation on an irregular floor. In the area to the west and south [1] these dips are more pronounced and to some extent have probably been emphasized by subsequent solution.

The chief stratigraphic differences in altitude throughout the district are due to faulting. Compared with the Ozark region as a whole, the eastern portion is most intricately faulted.

A pronounced belt of faulting enters Missouri from Illinois, traversing Perry and Ste. Genevieve Counties and striking northwest toward the Missouri River. It is a fault zone, in places several miles wide, which shows a maximum displacement of 2,000 feet (610 meters), with the downthrow to the northeast. Striking northeast from a point near Irondale is a major fault which passes west of Bonneterre and intersects the fault zone just mentioned near Valles Mines. The downthrow is to the northwest, and this fault bounds the productive area on the west. Westward from Irondale another fault zone strikes almost directly west into Crawford County. Within the lead district there are several faults, but the displacement on most of them is of minor extent. The accompanying map (fig. 11) shows the faults as known to date. They are both premineral and postmineral.

There is no evidence of direct association of the faulting with mineral deposition. The major system of faults in Ste. Genevieve and Perry Counties does not show any mineralization along the fault planes, and there are no disseminated deposits in the immediate vicinity. Likewise, the fault planes within the lead district do not show mineralization, and the distribution of the ore bodies is apparently not controlled by them. Where a fault is of postmineral age and has dislocated an ore-bearing bed some crushed and rounded galena occurs as drag ore in the gouge.

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[1] Bridge, Josiah, Geology of the Eminence and Cardareva quadrangles: Missouri Bur. Geology and Mines, 2d ser., vol. 24, pp. 160 and 163, 1930.

During the major movements of the Ozark region the Bonneterre formation has been fractured, and well-defined joints having little or no displacement are encountered in mining. It is usual for the ore bodies to follow a system of such joints. In many places the joints have been weathered and oxidized for several feet back from the fracture plane, and such oxidation extends downward through the Bonneterre formation to the Lamotte sandstone. Solution has widened many of the fractures, and these where open are usually strong watercourses.

The most abundant joints strike between N. 54° W. and N. 83° W. The next most abundant strike between N. 16° E. and N. 45° E., most of them between N. 37° E. and N. 45° E. The joints occur in zones in such a manner that a group of closely spaced, well-defined joints adjoins areas in which the joints are few and far apart.

## ORE DEPOSITS

The ore occurs almost exclusively in the Bonneterre formation, but a minor portion is found in the upper beds of the Lamotte sandstone. The deposits are large flat, tabular, blanketlike ore bodies, varying in thickness and width according to the nature of the host rock. Mineralization has been restricted largely to the dark beds that carry organic material, there being little or none in the light-colored dolomite. Workable ore bodies as much as 1,000 feet (305 meters) in width and more than a mile (1.6 kilometers) in length have been mined. The thickness of the mineralized rock varies. In many places it is restricted to a minable height of 6 feet (1.8 meters); in others stopes have been mined to a height of 125 feet (38 meters). In this height the beds vary in mineral content, some being practically barren, while in others the dolomite and shale have been largely replaced. In some of the shale beds replacement has been almost complete. The lower portion of the Bonneterre was apparently the most favorable part of the formation for deposition, and the most persistent mining horizon is not far above the Lamotte sandstone.

The ore occurs (1) disseminated through the dolomite, shale, and chloritic rock; (2) in horizontal sheets along bedding planes; (3) in small vugs and cavities; (4) lining the walls of small fractures or joints.

By far the major portion of the ore is disseminated through the rock. It occurs as small individual crystals, and only where the replacement was nearly complete is there massive ore. To some extent where replacement has been active along bedding planes the ore occurs in sheets. To a lesser extent, small cavities and joint planes are lined with small crystals of ore.

*The ore.*—Galena is the dominant mineral throughout the area. With it is associated pyrite. Chalcopyrite and sphalerite occur in minor quantities. Sphalerite is most abundant in the ores in the vicinity of Leadwood, but some of the ore does not contain any. Calcite occurs sparingly as a gangue mineral. The grade of the ore assays 3 to 4 per cent of lead, and the concentrates run over 70 per cent of lead. The ore is practically nonargentiferous, the concentrates carrying about 1 ounce of silver to the ton (31 grams to the metric ton).

In the Fredericktown area the mineralization differs markedly in some of the deposits. Here the replacement product is largely iron sulphide, with which are associated the sulphides of lead, copper, nickel, and cobalt. Though this ore varies widely in composition, a general average approximates 2 per cent of lead, 2 per cent of copper, 1 per cent of nickel, and 0.8 per cent of cobalt. These deposits follow the contact between the Lamotte sandstone and Bonneterre dolomite as narrow bands where these formations lap against irregular knobs of pre-Cambrian igneous rocks. This ore is more massive than in any other portion of the field, and much of the rock has been almost entirely replaced.

*Distribution of productive ore bodies.*—Production has been obtained from relatively small areas throughout the region in which the Bonneterre dolomite crops out. The areas from which most of the production has come are shown in Figure 11.

At Annapolis, in Iron County, some 25 miles (40 kilometers) southwest of Fredericktown (outside the area shown on the map), a low-grade deposit of typical disseminated ore has been mined for a distance of some 1,800 feet (549 meters). It lies in the pre-Cambrian valley between two porphyry ridges, where the Bonneterre dolomite crops out.

In much of the area of the St. Francois Mountains the Bonneterre occupies the valleys, and the region is potential lead territory, although but little production has come from this part of the district.

The chief productive area reaches from Bonneterre to a point about 3 miles (4.8 kilometers) southeast of Elvins, a distance of approximately 9 miles (14.4 kilometers). It extends from Leadwood on the west to a point about 1 mile (1.6 kilometers) east of Esther, a distance of approximately 7 miles (11.2 kilometers). (See area 2, pl. 6.) There is, however, much territory that has not been thoroughly drilled or tested.

*Prospecting and development.*—Prospecting is usually done with surface diamond drills, though churn drills are used occasionally. In untested areas the entire hole is cored. In better-known areas the holes are often "plugged" (the core ground up

and washed out as sand), then cored through the ore horizon into the Lamotte sandstone. The cores are usually treated in one of the following ways: (1) They are ground and assayed for lead and zinc; (2) the lead and zinc content is estimated by an experienced man by visual inspection, and the cores are stored for reference; (3) the cores are split longitudinally, and one-half is assayed for lead and zinc and the other half stored for reference. Sludge samples of the diamond-drill cuttings are occasionally assayed for lead as a check against the core determinations. Churn-drill cuttings are assayed for lead and zinc.

In development surface drilling is supplemented by underground diamond drilling and by drilling holes with heavy-duty air drills using short lengths of threaded drill steel that are added as the hole deepens. By the latter method holes as much as 80 feet (24 meters) in length have been drilled, and their average length is 35 feet (11 meters). Drilling is more economical and more efficient for prospecting than drifting. Some underground development is also accomplished by drifts and here and there by raises and winzes driven from existing mine workings to ore disclosed by drilling.

*Mining and milling.*—Mining is done by the open stope and pillar method. The stopes begin at the end of the development drifts that have been driven to the edge of an ore body. Jack hammer air drills are used in both drift and stope work. The ore is loaded into mine cars ranging from 1 to 3½ tons (0.9 to 3.2 metric tons) in capacity, both by hand shoveling and by mechanical loaders. Most of the tramming is done by electric trolley locomotives. Mules are used only from loading points to near-by gathering tracks. The ore is raised to the surface in skips having a capacity of several tons by means of electric hoists.

In the early days all ore was shipped direct to smelters. Concentrating mills have been used for about 60 years. During the last 20 years practically all of the ore has been concentrated, and no smelting ore has been sorted. The mills are usually located near the shaft mouths. At the present time there are seven mills in the district, six in the principal productive area and one near Mine Lamotte. The capacities of the mills range from 1,000 to 5,200 tons (907 to 4,717 metric tons) to the day of 24 hours. The Mine Lamotte mill uses flotation only; the other six use both gravity and flotation concentration. Gravity concentration is effected entirely by tables, no jigs being used. Various types of standard flotation machines are used.

The ores are easily treated. There are no interfering minerals, though considerable pyrite and varying amounts of sphalerite are associated with the galena. The River Mines and Leadwood

mills make zinc concentrates. The others do not have commercial quantities of sphalerite in their present mill feed. The lead concentrates run up to 75 per cent of lead, and the tails run as low as 0.08 per cent of lead.

Each mill of the St. Joseph Lead Co. is situated at an ore-hoisting shaft, and all ore for the mill is hoisted through that shaft. The mill of the St. Louis Smelting & Refining Works is supplied with ore from the shaft at the mill and with ore brought by railroad from National shafts Nos. 7 and 8, about 4 and 3 miles (6.4 and 4.8 kilometers), respectively, south of the mill.

The mine workings at Bonneterre and Mine Lamotte are not connected underground with any other mine workings. All the other mine workings are connected underground. The routing of ore from the working face to the hoisting shaft is determined by the management.

*Origin.*—There is great diversity of opinion and an extensive literature dealing with the origin of these ores. On one hand, the mineralizing solutions are believed to be of igneous origin; on the other hand, they are regarded as of meteoric origin, and their metallic content is thought to have been derived from the sedimentary rocks through which the waters have circulated.

The most recent exponents of a magmatic origin for both the solutions and their metallic content have been J. E. Spurr and W. H. Emmons. Emmons's ideas are more in line with the older views of Percival, Jenney, and Pirsson, who believed that the ores were deposited by ascending hydrothermal waters. Spurr regarded them as injections of ore magmas.

The advocates of the meteoric origin of the mineralizing solutions fall into two sharply differentiated groups. One group, represented by Winslow, Buckley, and Buehler, emphasize the rôle of descending meteoric waters. According to this view descending cold waters leached lead from the overlying sedimentary rocks as they were eroded and concentrated it in the underlying rocks. Though this theory seemed satisfactory to explain the shallow deposits, both Winslow and Buckley combined with it an artesian circulation in arriving at a satisfactory explanation of the disseminated ores.

The other group of exponents of meteoric waters ascribe the mineralization to an ascending artesian circulation which derived its metallic content from the rocks through which the waters circulated. This theory was early advanced by Van Hise and Bain and later greatly elaborated by Siebenthal.

All the advocates of meteoric waters as the mineralizing agents regard the pre-Cambrian rocks as the original source of the metals. The disintegration of these rocks and the transpor-

tation of the lead in solution by streams to the surrounding seas in which the Paleozoic sediments were being deposited are regarded as having furnished the lead in those sediments.

## ACKNOWLEDGMENTS

Substantial contributions to the foregoing account of the district were made by W. H. Comins, local manager of the St. Louis Smelting & Refining Works.

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# THE IRON-ORE DEPOSITS OF IRON MOUNTAIN, MISSOURI

By M. C. Lake

ABSTRACT

Iron ore has been produced from the Iron Mountain deposits for nearly a century. The ore occurs as irregular bodies within masses of pre-Cambrian andesite porphyry and in a basal conglomerate of Cambrian age derived from the pre-Cambrian ore bodies.

The primary ore consists principally of hematite with as much as 12 per cent of magnetite and small amounts of apatite and tremolite. Later minerals present in the ore are calcite, garnet, and quartz, which principally replace the apatite and tremolite.

Recent exploration has developed large bodies of ore within the andesite porphyry.

The ore as mined contains 43 per cent of iron and is concentrated to a shipping grade of 51 per cent.

The origin of the ore is ascribed to solution and stoping of the andesite porphyry by the ore-bearing solution, which crystallized in place.

Magnetic and electrical surveys have proved of value in exploration.

## INTRODUCTION

*Location.*—Iron Mountain, Missouri, is on the Missouri Pacific Railroad, 84 miles (135 kilometers) southwest of St. Louis. The Iron Mountain mine is in sec. 31, T. 35 N., R. 4 E., near the southwest corner of St. Francois County.

*History.*—The Iron Mountain tract, consisting of about 25 square miles (64.7 square kilometers), or, roughly, 16,000 acres (6,475 hectares), was originally acquired by Joseph Pratt from the Spanish Crown. Title was confirmed by Congress in 1836. Shortly afterward the property was sold to the Missouri Iron Co. and later to the American Iron Mountain Co., which was formed in 1845. Production began in 1845 and has been more or less continuous since that date. About 4,500,000 tons (4,572,000 metric tons) of ore has been shipped from the property, and the maximum annual production was 269,480 tons (273,803 metric tons), in 1872. The St. Louis, Iron Mountain & Southern Railway, now a part of the Missouri Pacific system, was built to the property from St. Louis in 1857. In 1869 the company was reorganized as the Iron Mountain Co. The M. A. Hanna Co. took control of the property April 1, 1927, through its subsidiary the Missouri Ore Co., and began intensive study and exploration of the ore deposits on this tract.

*Topography.*—The Iron Mountain mine is in a rugged, hilly, wooded district locally known as the St. Francois Mountains. The mine is about 1,100 feet (335 meters) above sea level, but peaks in the vicinity rise to a maximum altitude of about 1,600 feet (488 meters). Most of the high knobs consist of pre-Cambrian igneous rocks, which are separated by narrow valleys filled with Cambrian sediments.

## GENERAL GEOLOGY

The oldest rocks of the Iron Mountain district are of pre-Cambrian age and consist of granite, andesite porphyry, rhyolite intrusives, and lava flows consisting of rhyolite, dacite, and diorite. Dioritic and andesitic dikes intrude the older series. The pre-Cambrian rocks are overlain by Cambrian sediments consisting of conglomerate, limestone, and sandstone. These sediments are practically flat-lying and surround hills of pre-Cambrian rocks, but in places they are tilted to some extent adjacent to the porphyry or granite knobs, probably owing to settlement during the period of consolidation. It is very probable that the entire district was submerged within a relatively short period of time just prior to the Cambrian deposition, as that would explain the ruggedness of the pre-Cambrian contour of the area of the high ridges and steep-sloped valleys now filled with the sediments. During Paleozoic time the area was elevated and eroded to its present topographic expression.

Pre-Cambrian rocks occurring at the Iron Mountain mine include andesite porphyry, iron ores, dikes of green andesite and gray dacite, dacitic flows, rhyolite flows, and intrusive rhyolite. The principal igneous rock of Iron Mountain is the andesite porphyry, a massive, dense reddish intrusive rock. All of the primary iron ore at Iron Mountain occurs within this andesite porphyry. The groundmass is felsitic, and the phenocrysts are plagioclase feldspar with a minor percentage of ferromagnesian silicates. The rock is jointed along planes roughly parallel to the present erosion surface. This jointing is suggestive of flow lines with later shrinkage cracks.

## THE IRON ORES

There are two types of iron ore at Iron Mountain, the primary and the conglomerate ores.

The primary ores are crystalline iron oxides composed principally of hematite but containing some magnetite in proportions ranging from practically nothing up to 12 per cent of the total weight of the ore. Contemporary minerals are apatite

and tremolite, which are distributed throughout the ore like phenocrysts of an igenous rock. The ore, after deposition in the andesite porphyry, has been replaced and modified to some extent by the introduction of calcite, andradite garnet, and quartz. This second mineralization affected especially the


FIGURE 12.—Geologic map of Iron Mountain mine, Missouri. A to E, lines of sections shown in Figures 13 to 17. Contours indicate magnetic intensity

apatite and tremolite and reduced the phosphorus content of the ore.

The conglomerate ores represent the eroded and transported primary ores and are now found at the base of the Cambrian sediments lapping around the hill. The fragments of ore in the conglomerate range from those the size of sand grains to masses

weighing many tons. The conglomerate ores are found mainly in the vicinity of present outcropping or known deposits of primary ores. A considerable tonnage of these ores has been mined. The principal production has been derived from an old mine east of Big Cut and from more recent developments tributary to the A shaft. (See fig. 12.)

A large tonnage of ore was mined by open-pit methods from the Big Cut area. (See section E, fig. 17.) According to early descriptions, this deposit was practically a solid dome-shaped mass of ore at the surface. As mining progressed, however, it

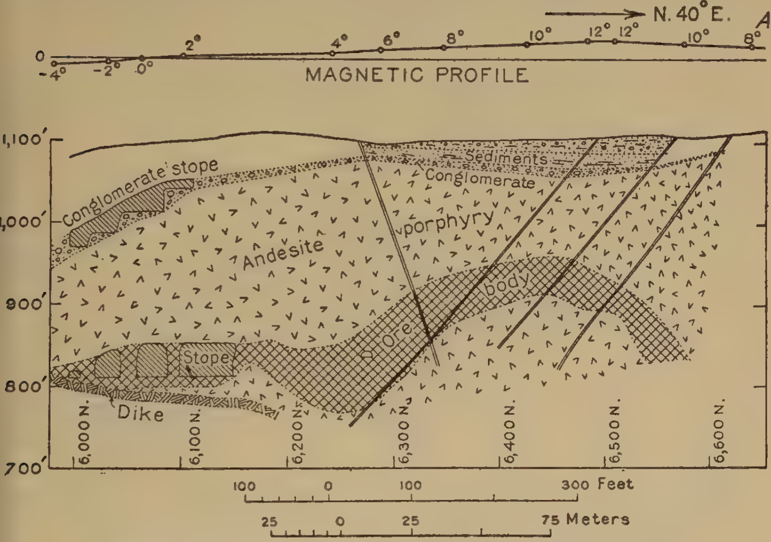


FIGURE 13.—Geologic section A through Iron Mountain mine

was found that the core of the deposit consisted of a mixture of ore with high-grade veins extending into the massive andesite around the edges of the dome. This deposit probably averaged over 60 per cent of iron. Portions of it were very high in phosphorus on account of the occurrence of numerous large hexagonal crystals of apatite here and there within the deposit. Diamond drilling from the bottom of the Big Cut has shown that although there is a mixture of porphyry and ore for a distance of about 100 feet (30 meters) below the present surface, the ore body does not continue downward vertically. Exploration around the edges to determine whether the veins continue down around the core to greater depths has not been complete.

The Hayes Cut deposit consisted of a wedgelike mass of solid iron ore of about the same quality as that at Big Cut. It was

about 400 feet (122 meters) long and about 50 feet (15 meters) thick at the surface and dipped about 30° W. About 400 feet (122 meters) down from the surface this deposit pinched out, and drilling to determine its continuity with depth has been disappointing. The footwall consists of a mixture of porphyry and ore with a few veins of almost pure tremolite cutting through the porphyry. This deposit is now exhausted except for some of the low-grade footwall material, which is being mined by

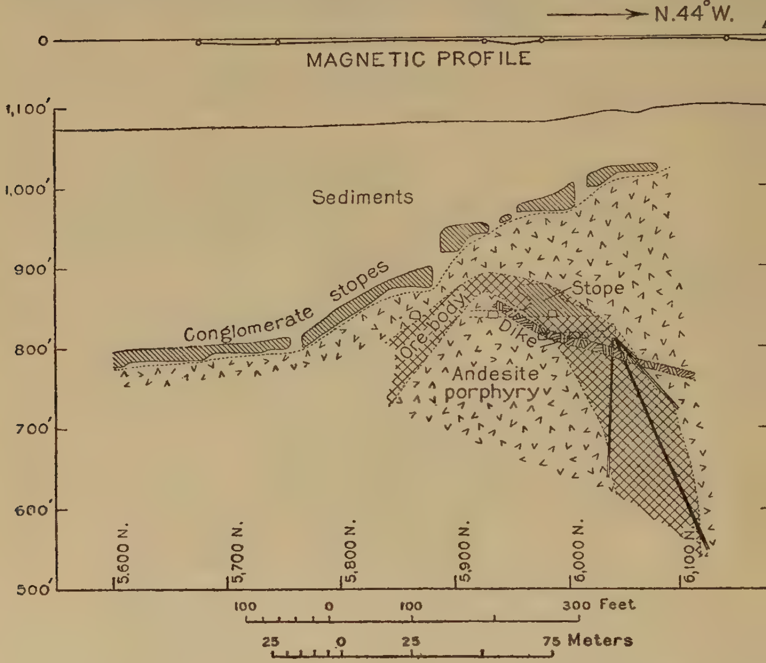


FIGURE 14.—Geologic section B through Iron Mountain mine

open-pit methods and must be beneficiated to produce a high-grade concentrate. (See section D, fig. 16.)

Since 1927 the M. A. Hanna Co. has been successful in proving up two new ore bodies. One of these is southeast of the Hayes Cut and has been developed and mined down to a level 250 feet (76 meters) below the collar of the A shaft. This ore body is illustrated on the map (fig. 12) and on cross sections A and B (figs. 13, 14). Its shape is that of an inverted cup, and mining has proved the continuity of ore across the top of the dome. Drilling has disclosed ore in the vertical downward extensions of the dome for 250 feet (76 meters) below the bottom level.

The second ore body discovered by the M. A. Hanna Co. lies to the north of the Hayes Cut, adjacent to the railroad, and is illustrated by cross section C (fig. 15). This ore body starts out at the pre-Cambrian surface as a narrow vertical vein several hundred feet long, striking N. 30° W. In depth the deposit widens. Drilling has proved its continuity to a depth of about 500 feet (152 meters) below the surface, where it is approximately 200 feet (61 meters) wide.

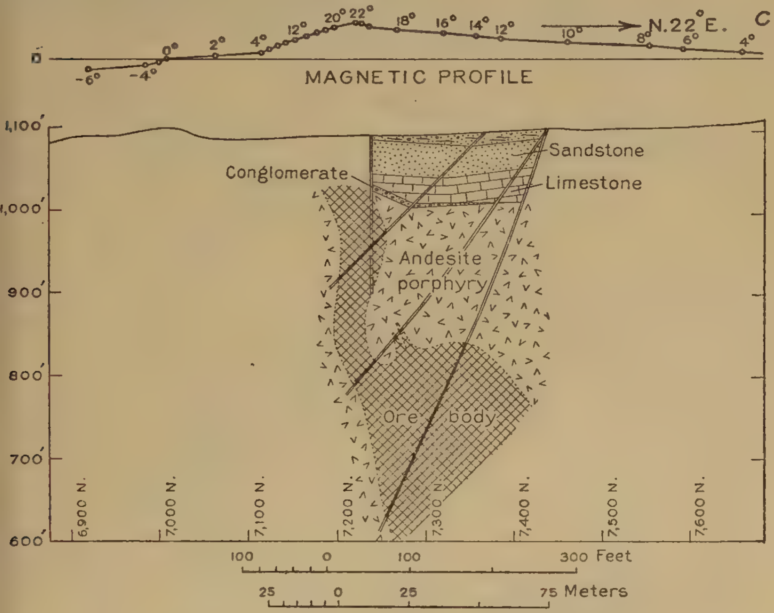


FIGURE 15.—Geologic section C through Iron Mountain mine

The ore body at the A shaft and the one north of the Hayes Cut are not pure enough to be shipped as high-grade ore and must be beneficiated to increase the iron content and reduce the silica content. The ore consists to some extent of a mixture of ore and porphyry, but the ore is contaminated principally by garnet, which must be eliminated to reduce the silica content. Both the hanging wall and the footwall of the deposit in the A shaft consist of a breccia of ore and porphyry from a few feet to 20 feet (6 meters) thick. The breccias in this deposit, in the center of the Big Cut and the footwall of the Hayes Cut, are all typical solution breccias rather than of the dynamic type.

## MINING

The ore at the Big Cut and Hayes Cut was mined by open-pit methods. Considerable hand sorting must have been done during the mining of these deposits to produce the high-grade ore that was shipped from the property during its early history.

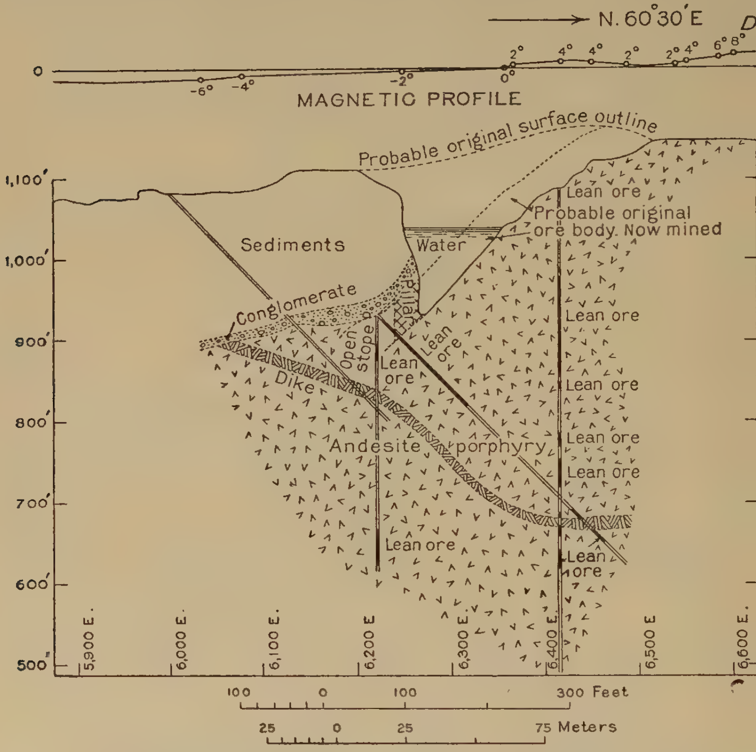


FIGURE 16.—Geologic section D through Iron Mountain mine

Large dump piles of lean cobbed material are found adjacent to these mines.

The deposit at the A shaft is mined by the open stope and pillar method, with underground scrapers attached to electrically driven tugger hoists. The ore is scraped from the working face to chutes and drawn off on the 250-foot (76-meter) level, whence it is transported to the A shaft, hoisted to the surface, and dumped directly into the mill bin. The ground stands very well, and no timbering is required in the development drifts or in the stopes. Electric power is used for haulage and pumping underground

and for operating the hoist and mill motors. The power is generated in a Diesel engine plant at the mine.

A small tonnage has been mined recently by open-pit methods in the footwall of the Hayes Cut deposit and trammed by truck to the mill.

The conglomerate ore body adjacent to the A shaft is exhausted. A substantial tonnage was mined in this area by the room and pillar method. The stopes have been extended to the limits of the ore body, which gradually thins out and decreases in grade down the dip from the 250-foot (76-meter) level.

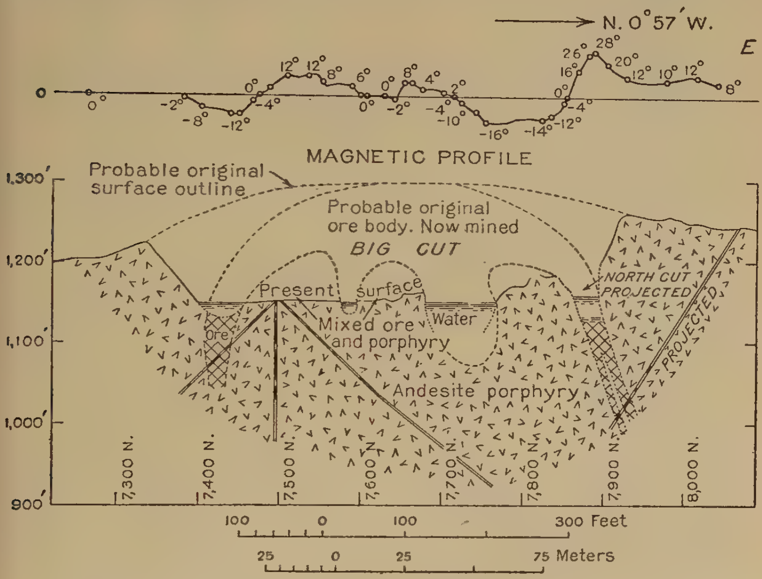


FIGURE 17.—Geologic section E through Iron Mountain mine

## MILLING

The ore as mined from the A shaft area averages about 43 per cent of iron. Beneficiation brings it up to about 51 per cent of iron with 13.5 per cent of silica. This is accomplished by first crushing down through the jaw crusher and rolls to about ¾ inch (1.9 centimeters), and treating the coarse sizes on Hancock jigs and the small sizes on tables. From 1½ to 2 tons of crude ore is required to produce 1 ton of concentrates. The present capacity of the mill is 500 tons (508 metric tons) of crude ore to the shift.

The following is a complete analysis of 100 feet (30 meters) of dried ore from drill hole 3101:

| | |
|---|---|
| Total iron | 49.65 |
| Ferrous iron | 2.80 |
| Ferric iron | 46.85 |
| Silica | 14.38 |
| Phosphorus | .009 |
| Manganese | .49 |
| Alumina | 1.40 |
| Titanic acid | 1.08 |
| Lime | 7.65 |
| Magnesia | 1.30 |
| Sodium oxide | .13 |
| Potassium oxide | .08 |
| Copper | .003 |

A complete analysis of 28,177 tons (28,629 metric tons) shipped during a part of 1928 is as follows:

| | |
|---|---|
| Total iron | 51.32 |
| Silica | 13.55 |
| Phosphorus | .023 |
| Manganese | .35 |
| Alumina | 1.88 |
| Titanic acid | 1.10 |
| Lime | 4.55 |
| Magnesia | 1.23 |
| $CO_2$ loss | 2.92 |
| $H_2O$ loss | .93 |
| Moisture | 2.96 |
| Sulphur | .007 |
| Nickel | .006 |
| Chromium | None. |
| Vanadium | .04 |
| Loss on ignition | 2.82 |

This ore contains 7.60 per cent of magnetite.

All Iron Mountain ore is shipped to the furnaces of the St. Louis Gas & Coke Corporation at Granite City, Illinois.

## ORIGIN OF THE ORE

Dr. Edward Steidtmann, professor of geology at Virginia Military Institute, assisted the writer in studying the geologic problems at Iron Mountain during 1928 and made a very thorough petrographic study of the rocks and ores for the purpose of determining the origin of these deposits. Dr. Steidtmann's theory of the ore origin, with which the writer agrees, is here condensed from his private report.

The irregularity of form in the deposits suggests that they were produced by replacement. The commonly accepted picture of this process as replacement of solid phase by solid phase is not in accord with the textural characteristics of the ores. Liquid ore phases may have worked into the porphyry along the existing joint systems or other openings from below. They replaced the solid porphyry but continued in the liquid phase and then crystallized out. After crystallization both ore and porphyry were acted upon by the garnetizing, carbonating, silicifying solutions, which brought about a great deal of replacement of the usual type. This replacement was very unevenly distributed, and the proportions of minerals deposited are extremely variable.

It is thought that the porphyry masses subsided along upward-curving fractures. The general result would be comparable to causing a slight separation of two cups telescoped over one another. The large hollow formed at the top of the under cup and the narrower opening around the sides would be occupied by the ore solution. Further sloughing from the walls of the chamber by processes of stoping similar to those which cause rock to spall and fall from an unsupported roof would enlarge these ore chambers and open up irregular crevices in the roof. By such a process of stoping and solution the porphyry solution breccia commonly found above the ore masses could have been formed. Solution of the porphyry and the substitution of a liquid ore solution would be an essential part of this process. Augustus Locke has offered a somewhat similar explanation for pipe-shaped sulphide ores that have a blind upward termination. Such a process of solution of the porphyry and enlargement of liquid solution chambers by fracturing and stoping would allow for very great variation in shape and extent of the resulting ore bodies. The great irregularity of shape of most of the ore bodies points to replacement of the porphyry by ore, but a great deal of the ore has the porphyritic texture of an igneous rock which has crystallized out of an immobile solution. The theory offered is that hot ore solutions entered the porphyry from below along existing fractures, which were not as fully developed as now. The solutions dissolved the porphyry, forming chambers filled with ore-bearing solution. Fracturing and sloughing along the walls of the chambers followed, and this led to further invasion of the porphyry by the ore-bearing solutions working

outward from the solution chambers. In this way each ore chamber became enveloped by a solution breccia. Ore juices penetrating beyond the solution chamber also effected replacement. The solution in the chamber and in the veinlets and tongues which project beyond it finally solidified. Hot juices of a different order later permeated the ore and the porphyry, causing carbonation, garnetization, and silicification. In the ore bodies it was mainly the apatite and the tremolite that were affected.

## MAGNETIC SURVEYS

Inasmuch as the Iron Mountain ores had been found to contain a small percentage of magnetite, it was thought advisable at the time the M. A. Hanna Co. took over the exploration of this property to make a very careful magnetic survey of the area in the vicinity of the Hayes and Big Cuts. This work was done by A. E. Walker, field geologist for the company. The area subject to investigation was carefully surveyed by transit to establish a 100-foot (30-meter) coordinate system, and north-south and east-west dip needle readings were taken along coordinate lines at intervals of 25 feet (7.6 meters). The ordinary Gurley dip needle was used. Sundial compass readings were taken at 100-foot (30-meter) intervals. This magnetic work proved to be of great assistance in the discovery of ore bodies and was fundamental in guiding exploration, which was successful in locating the two new deposits at the A shaft and north of the Hayes Cut. Although not all the magnetic areas have yet been explored, the experience gained from drilling the two deposits suggests hopeful results from other known magnetic areas.

The magnetic intensities have been platted on the accompanying map (fig. 12) by the contour method. Magnetic profiles have also been platted on the cross sections in Figures 13–17. Comparison of these magnetic intensities with the position of the ore bodies shows that there is a direct relationship between the two. The ore body shown in cross section C (fig. 15) was discovered under a depth of about 60 feet (18 meters) of Cambrian sediments. The ore body in the vicinity of the A shaft was discovered under a thickness of about 30 feet (9 meters) of sediments and 100 feet (30 meters) of andesite porphyry. The south end of the A shaft ore body lies in either a neutral or a negative area. The north end underlies a positive 12° area. To the southwest of the A shaft ore body is an extensive area of negative attraction. It is thought that possibly ore may be found to extend underneath this negative area, but this has not yet been explored.

A geophysical survey of the property was made by the Physical Exploration Co., of Madison, Wisconsin, about the time the drilling was suspended. It was desired to determine whether geophysical investigation would add any information to that already obtained by the dip-needle study and exploration. It was found that the applied-potential method, with one electrode placed at the ore horizon in the drill holes and the other at some distance from the hole, served to outline the extent of the ore bodies rather accurately. The ore proved to be a good conductor compared with the andesite rock, and the electrical methods have extended the outlines of ore bodies indicated by the original magnetic survey. The two methods of geophysical study have demonstrated their practical application in arriving at an understanding of the geology in its major aspects, with effective results in finding commercial deposits of iron ore at Iron Mountain.

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[See bibliography on Pilot Knob (p. 73)]

# THE IRON DEPOSITS OF PILOT KNOB, MISSOURI

By Edward Steidtmann

ABSTRACT

The Pilot Knob iron deposits have produced more than 1,500,000 tons (1,524,000 metric tons) of ore since 1848.

The ore occurs in pre-Cambrian rocks consisting of felsitic porphyries, breccias, and "ore beds." The "ore beds," which have produced nearly all the ore, were originally deposited in shallow water and may have contained volcanic ash. Ore-bearing solutions replaced and altered to some extent all these rocks, but the most extensive replacement by hematite occurred in the fine-grained sediments. The deposition of hematite was accompanied by sericitization and silicification of the denser rocks.

## LOCATION AND TOPOGRAPHY

Pilot Knob is about 5 miles (8 kilometers) south of Iron Mountain, Missouri. It is a conical peak whose moderate southwest slopes reflect the dip of the underlying beds. The northwest slopes are steep to precipitous. The summit is about 1,500 feet (457 meters) above sea level and about 600 feet (183 meters) above the floors of the adjacent valleys.

## PRODUCTION AND HISTORY

Over 1,500,000 tons (1,524,000 metric tons) of ore has been mined at Pilot Knob. Mining started in 1848 and continued without interruption until 1890. It was resumed in 1910. Most of the ore was taken from the lower and upper ore beds. Conglomerate ore was also productive.

The ore beds are finely banded alternations of dark-gray crystalline hematite and brownish-red ferruginous fine-grained quartz. The shipments of six months in 1885 averaged 58.11 per cent of iron, 17.02 per cent of silica, 0.013 per cent of phosphorus, 2.59 per cent of alumina, 0.077 per cent of sulphur, 0.015 per cent of lime, and 0.015 per cent of magnesia. Some of the hand-picked "conglomerate" ore shipped in 1911 ran 56.03 per cent of iron, 10.15 per cent of silica, 4.37 per cent of alumina, and 0.021 per cent of phosphorus. The weathered portions of this ore ran about 7 per cent less in silica.

The bedded ores were first mined in an open cut on the northwest side of the hill. From this open cut tunnels were driven down the incline, following the ore, and a shaft was sunk on the southwest slope. In recent years a great deal of the lean, siliceous

ore and overlying breccia have been quarried in the open cut on the northwest side for road building. The conglomerate ore was quarried by open-cut methods.

## GEOLOGIC SUCCESSION

The peak is underlain by pre-Cambrian flows and mechanical sediments, and its base is covered by Cambrian limestone. A talus deposit of hematite ore and felsite porphyry, called conglomerate ore, lies between the limestone and the pre-Cambrian

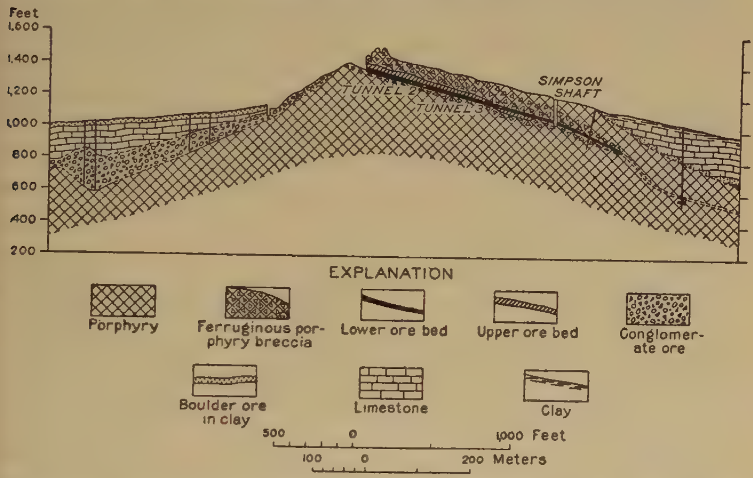


Figure 18.—North-south profile of Pilot Knob, Missouri. (After G. W. Crane, Missouri Bur. Geology and Mines, vol. 10.)

rocks on the northwest side of the peak. It is estimated to extend over 400,000 square feet (37,161 square meters) and to have a maximum thickness of 200 feet (61 meters). The pre-Cambrian has been subdivided as follows, starting from the top:

| | Feet | Meters |
|---|---|---|
| Upper felsite porphyry and felsitic rocks of uncertain origin, outcropping on southwest side of peak near Simpson shaft. (See cross section, fig. 18.) Thickness at shaft, about | 50 | 15 |
| Upper ferruginous silicified breccia with local masses of finely laminated, bedded, and cross-bedded silicified and ferruginous sediments, which has produced a little ore | 100 | 30 |
| The upper ore bed. Laminated silicified and ferruginous sediment grading laterally and upward into silicified ferruginous breccia. Contains some breccia locally. Has produced ore | 10–20 | 3–6 |
| Sheared sericitic layer | 1–3 | 0.3–0.9 |
| The lower ore bed. Laminated silicified ferruginous sediment like the upper ore bed. Ripple marks, rain prints, and sun cracks are locally common | 6–30 | 1.8–9 |
| Footwall porphyries. | | |

## STRUCTURE

The contact between the footwall porphyries and the overlying ore bed is exposed on the northwest side of the peak about 150 feet (45.7 meters) below the summit. It dips about 17° SW., without showing any marked undulations. The beds above this plane are conformable in appearance.

## PRE-CAMBRIAN ROCKS AND ORES

The footwall porphyries are reddish-brown felsites of extremely fine grain. Phenocrysts are scarce. Some have been identified as rhyolites. Flow lines, spherulites, and amygdaloids are found locally. Extensive silicification and sericitization have taken place. Locally the sericite is present in porcelainlike nodules. An impregnation of fine-grained reddish pigment, locally agatelike in distribution, is common. Veinlets of compact blackish-gray hematite are occasionally found. On the northwest side an attempt to mine a vertical vein was made, but it proved unprofitable.

The lower ore bed is hard, compact, and evenly laminated. Thin layers of fine-grained crystalline bluish-gray to steel-gray hematite and a little quartz and sericite alternate with laminae composed of quartz, sericite, reddish hematite pigment, and a little crystalline hematite. The laminae are commonly about 0.1 inch (2.5 millimeters) in thickness. The hematite crystals are thin laths about 0.01 inch (0.25 millimeter) in cross section, with wedge-shaped terminations. The quartz grains are interlocking, irregular in outline, and not fragmental in appearance. Doubly terminated quartz crystals of microscopic size are found sparsely. In thin section tiny angular fragments are found occasionally and are rather abundant at certain horizons. They are silicified and sericitized, and their margins are replaced and embayed by crystalline hematite. Barite occurs sparsely and in some places forms thin films along the joints. Tourmaline and apatite have also been identified. The phosphorus and sulphur contents, however, are extremely low. Locally ripple marks, rain prints, and sun cracks are well developed in the lower part of the formation. The ripples are symmetrical ridges about 0.1 inch (2.5 millimeters) in height with wide troughs. The distance from ridge to ridge averages a quarter of an inch (6.3 millimeters).

Crane described a sericitized sheet as being above the lower ore bed in the big cut. He gives the thickness as 1 to 3 feet (0.3 to 0.9 meter) and the color as ash-gray to chocolate, and states that it is traversed by shear planes parallel to the bedding and locally by S-shaped fractures.

The upper ore bed is like the lower ore bed in structure and composition. Fragments are more common, and it grades upward and laterally into silicified ferruginous breccia. The thickness as mined ranged from 10 to 20 feet (3 to 6 meters), and the bed was recognized down the dip for a distance of about 740 feet (225 meters). The greatest thickness was found near the east end of the open cut on top of the hill. Both silica and hematite show the replacement characteristics of the lower ore bed. The fragments are silicified and sericitized. Their margins are replaced and embayed by crystalline hematite.

The next overlying member is a coarse silicified ferruginous breccia about 100 feet thick with local bodies of finely banded material composed of silica and crystalline hematite like the underlying ore beds, from which the breccia is not sharply separated. The coarse fragmental parts show no sorting or bedding except a limitation in size of the boulders to less than a foot (0.3 meter) in diameter. The fine-grained phases, on the other hand, are banded and cross-bedded. They are not confined to any particular horizon. The fragments of the breccia are not rounded. Many of them are polyhedral, as if their shapes were made by intersecting joints. Vesicular, amygdaloidal, or other structures typical of volcanic eruptives have not been found. The fragments at the top of the hill seem to have lost their original constituents entirely, but down the southwest slope some felsites and porphyries were seen. On top of the hill the fragments are completely silicified and sericitized. Their margins are replaced by crystalline hematite. They are embayed by hematite and cut by tiny hematite veinlets. The fines are replaced by hematite more extensively than the fragments. The banded parts are like the lower ore beds, and a little ore has been taken from them in places.

Down the southwest slope of the hill the breccia is covered by quartz felsites and other brownish felsitic rocks without phenocrysts. At the shaft they are about 50 feet (15 meters) thick. These rocks have also been silicified, sericitized, and impregnated with a reddish pigment to a marked extent.

## PRE-CAMBRIAN HISTORY

The observed facts suggest the following geologic history: A succession of acidic lava flows was laid down. Locally a small body of water covered the smooth surface of a flow. A fine-grained clastic sediment like a thinly laminated clay was deposited. This may have accumulated from a succession of ash falls. The angular fragments present locally support the ash hypothesis. The water was shallow, as attested by rain prints

and sun cracks. Wave action as indicated by the ripples was very feeble. The even lamination speaks for a small protected body of water. The pool or lake was bordered by sheets of angular terrestrial slope wash of poorly sorted felsite porphyry. Much of this débris had been disintegrated from cold lavas, as shown by the presence of polygonal blocks shaped by intersecting joints. There is no evidence that any of it was pyroclastic. The slope wash of poorly sorted material was carried out over the quiet-water sediments as flood débris. New pools formed locally on the slope-wash débris, and in these more fine-grained laminated sediments were deposited. Wave action never was strong enough to rearrange the coarse débris. The area of sedimentation was finally covered by acidic lava flows.

After their deposition the materials were permeated by solutions which caused extensive alterations in all of them—silicification, sericitization, and hematitization. The most intensive alteration took place in the fine-grained sediments, and these furnished the ores. A little hematite was deposited in minute veins. The formation of crystalline hematite, the sericitization, and the intensive silicification of dense rocks, as well as the presence of tourmaline, are taken as evidences that the solutions were hot.

## COMPARISON OF PILOT KNOB WITH IRON MOUNTAIN

The primary ores of Pilot Knob constitute evenly banded sediments which were replaced by hematite, quartz, and sericite. Those of Iron Mountain (see pp. 57–61) consist of veins, sheets, convex lenses, and irregular bodies. They represent fissure fillings and replacement deposits in an intrusive andesite. In both localities the mineralizing solutions were hot. At Iron Mountain there is evidence of two epochs of mineralization. In the first hematite, magnetite, amphibole, and apatite were deposited. The process was much like an igneous intrusion. At the time of crystallization the ore solutions were a dense, viscous quiescent mass in which the earliest minerals to crystallize did not sink. In the second epoch there was extensive replacement of andesite and the nonmetallic constituents of the ore by calcite, quartz, and garnet. No evidence of sericitization has been found. At Pilot Knob apatite is scarce, and amphibole and garnet have not been observed. Here the evidence for two epochs of mineralization is not pronounced. All the rocks have been more or less silicified, sericitized, and hematitized. The most intense alteration took place in the fine-grained sediments. Mineralization was accomplished by high-temperature mobile solutions.

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# THE TRI-STATE ZINC-LEAD REGION

By Samuel Weidman

ABSTRACT

The ore deposits of the tri-State region are generally confined to the Mississippian Boone cherty limestone, which forms the surface rock in the eastern part of the region, about Joplin, but which is overlain by thick Pennsylvanian shale in the western part, about Picher.

The ore occurs as a cement in chert breccia, as vein fillings in fractured chert, and as replacement deposits. Two periods of silicification affected the rocks of the region; the earlier is represented by the angular fragments of white chert in the ore breccia; the later, associated with dolomitization and metalliferous deposition, is represented by the ore-bearing jasperoid that cements the breccia. The first period of silicification, when the Boone was at the surface, occurred in Mississippian time; the second period, associated with ore deposition, when the Boone was overlain by several thousand feet of strata, was probably late Mesozoic.

The ore bodies occur irregularly within a zone 50 to 150 feet (15 to 46 meters) in thickness, mainly in the upper half of the Boone chert. The ore zone is 100 to 150 feet (30 to 46 meters) below the overlying shale, except where the strata are downfolded. In the Picher district there is an abrupt fold, the Miami syncline, and the ore zone, instead of following the depressed strata, maintains the same level through the syncline, extending up through the upper part of the Boone and the overlying Mayes formation to the shale above. In the syncline ore high in lead is mined directly under the shale.

By far the richest mines of the region are centered about the Miami syncline, where deformation is greatest and where an extensive underlying granitic intrusive is indicated.

## INTRODUCTION

For the last 50 years the tri-State region has yielded from 50 to 80 per cent of the zinc of the United States and from 20 to 30 per cent of the zinc of the world. The zinc ore, sphalerite, contributes about 85 per cent of the total output of the region, and the lead ore, galena, 15 per cent.

The region (pl. 7) includes the adjoining portions of southwestern Missouri, southeastern Kansas, and northeastern Oklahoma, hence the name tri-State region. As defined on the map it measures about 37 miles (60 kilometers) from east to west and 27 miles (43 kilometers) from north to south. Within this area the ore deposits are grouped together in mining districts of various sizes, separated from one another by essentially barren ground.

The altitude ranges from about 730 feet (223 meters) where the Spring and Neosho Rivers leave the southwestern part of the region to a little above 1,200 feet (366 meters) on the

highest uplands in the southeastern part. The region is drained southeastward through the Spring and Neosho Rivers. The general dip of the strata, however, is to the northwest.

Physiographically that part of the region east of the Spring River is within the Ozark Plateau province, and the area west of the river is within the Osage Plains section of the Central Lowland province.

The climate of the region is of the midcontinent type of the temperate zone. The average monthly temperature ranges from 40° F. in winter to 80° F. in summer, with the minimum in winter from 0° to 15° F. and the maximum in summer often reaching 95° to 100° F. The winter temperature, however, is rarely low enough to affect the milling operations in the mining district.

The average annual rainfall is 40 inches (1 meter), the greater part of which falls in the summer, from April to September. The rainfall is sufficient to maintain a large local water supply, favorable for operating mills and flotation plants.

The prairie land west of the Spring River is devoid of trees except along the stream bottoms, but farther east, on the western slopes of the Ozark Plateau, there is a forest covering of dwarf oak amply sufficient for certain types of mining timber.

The mining district is well supplied with fuel and electric power. Natural gas from the Bartlesville district, Oklahoma, is available for domestic and industrial purposes. Coal is within easy reach from the Pittsburg district, Kansas, 25 miles (40 kilometers) to the north. A large pipe line from the Oklahoma oil fields extends through the central part of the district. There is an electric power station in the central part of the district, at Riverside, operated in part from local water power developed on the Spring River and in part from an auxiliary steam plant.

The general region affected by the mining industry has a population of about 100,000. The larger cities and their population, according to the census of 1930, are Joplin, Missouri, 33,454; Miami, Oklahoma, 8,064; Picher, Oklahoma, 7,773; Webb City, Missouri, 6,876; Galena, Kansas, 4,736; Baxter Springs, Kansas, 4,541; Commerce, Oklahoma, 2,608.

Joplin is the chief industrial and commercial city of the district. There are lead smelters at Joplin and Galena and near Quapaw.

Lead mining in the vicinity of Joplin began at Oronogo in 1851, though lead ore had been discovered in the region at a much earlier date. Although zinc ore was known to occur with the lead ore it was mined and smelted only to a very slight extent (100 tons (91 metric tons) of zinc metal) before 1870. From

1870 to 1879 Missouri produced 56,000 tons (51,000 metric tons) of zinc, most of which came from mines of the Joplin district, and the remainder from the Granby and Aurora districts.

Lead ore was known to occur along the Spring River, and small amounts were produced near Baxter Springs, Kansas, as early as 1870, but zinc ore was not mined until a few years later. The first important discovery of lead ore in the vicinity of the

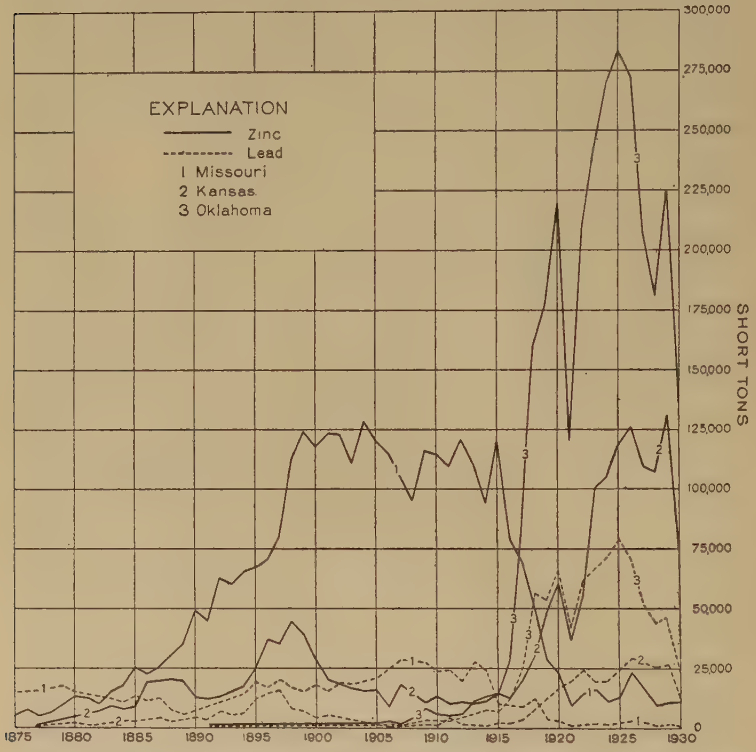



FIGURE 19.—Production of lead and zinc in tri-State region, 1875–1930. Compiled mainly from Mineral Resources of the United States

site of Galena was made in 1876, after which the locality became a very active center of production of both lead and zinc.

The earliest lead and zinc mining in northeastern Oklahoma was at Peoria in 1891, in what was then Indian Territory. The mines about Lincolnville and Quapaw, west of the Spring River, were started in 1906, and those beneath the shale at Commerce in 1908 and at Picher in 1914. Two-thirds of the mines are in the Quapaw and Peoria Indian reservations, mostly in the

Quapaw. About one-third of the ore produced is derived from lands still owned by Indians. The United States Geological Survey maintains an office at Miami, Oklahoma, for the purpose of supervising the leasing and mining of Indian lands.

With few exceptions, tri-State zinc and lead ores have been produced under the leasing and royalty system. In recent years as leases have expired there has been a tendency of operators to purchase the lands in fee. Leases are usually granted for "ten years and as long thereafter as lead and zinc minerals are found in paying quantities." The prevailing original royalty rate is 10 per cent. The size of the leased tracts varies from 20 acres (8 hectares) to several hundred acres, but the 40-acre (16-hectare) tract is the most common unit. The leases have generally required the milling of the ore from each lease in a separate mill. There is now a tendency toward consolidation of leased tracts for centralized milling. The largest of these consolidates 880 acres (356 hectares) into one milling unit.

The production of metallic zinc and lead in adjoining parts of the three States is shown by Figure 19. The maximum production of Missouri was attained between 1900 and 1915, and that of Oklahoma and Kansas between 1920 and 1930. About 20 per cent more ore has been produced from the area overlain by the Cherokee shale in Oklahoma and Kansas since 1915 than in the older districts about Joplin and Galena since 1860.

## GEOLOGY

### FORMATIONS

The three formations of special interest in connection with the ore deposits are the Boone chert, the Mayes formation, and the Cherokee shale. (See pl. 7.) Below the Boone chert is the Chattanooga shale, of variable thickness but increasing to the south. Below the Chattanooga is about 1,500 feet (457 meters), mainly dolomitic limestone, above the pre-Cambrian. The 100 to 200 feet (30 to 61 meters) of strata immediately under the Chattanooga appear to contain very few fossils, and their age is unknown but is possibly Devonian or Silurian. The lower 1,200 to 1,400 feet (366 to 427 meters) above the pre-Cambrian represents Ordovician and Upper Cambrian. The upper formations in the Picher district, including the Chattanooga shale, are shown in Figure 20.

*Boone formation.*—The Boone consists mainly of chert and limestone with a few thin seams of shale. There is a variable amount of dolomite in close association with the ore deposits. The average thickness of the formation in the Oklahoma part of the region is 362 feet (110 meters).

The lower 40 feet (12 meters) of the Boone is more shaly and less cherty than that above, and this lower part is referred to as the St. Joe member. The Short Creek oolite member is a fairly persistent bed from 2 to 10 feet (0.6 to 3 meters) thick, about 100 to 125 feet (30 to 38 meters) below the top of the Boone. The oolitic bed is generally silicified near the ore deposits. A greenish glauconitic limestone bed may be recognized in some of the mines and in drill cuttings at about 25 to 30 feet (8 to 9 meters) above the oolitic bed.

Within the Boone, especially in that part above the St. Joe member, the amount of chert ranges from 30 to 95 per cent of the rock. The highly silicified beds have been considered by some geologists to represent distinct stratigraphic horizons.

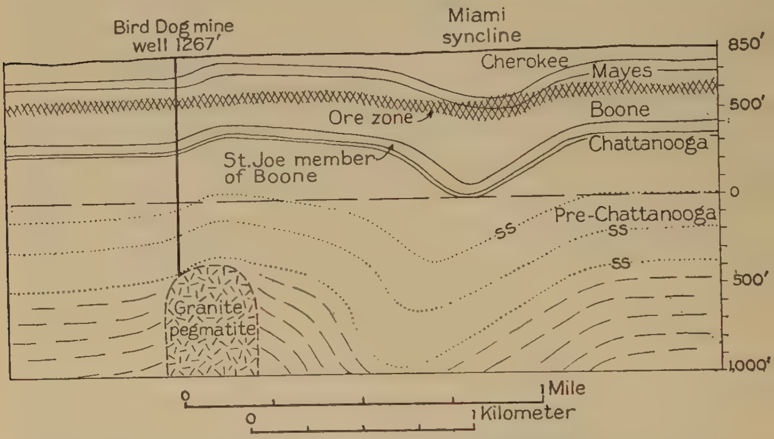



FIGURE 20.—Section showing upper formations in Picher district, Oklahoma, and relation of granite pegmatite to the Miami syncline and the ore zone. (After Weidman, Samuel, Oklahoma Geol. Survey Bull. 56, 1932)

There is, however, no uniformity in either the thickness or the lateral distribution of the highly silicified portions of the Boone, and it is likely that the chert zones, although having great lateral extent, do not form definite stratigraphic units.

The chert of the Boone has been generally recognized as of two ages—the "old chert," generally white, which forms the angular fragments in the ore breccia, and the "young chert," generally dark colored, which forms with the ore the cement of the breccia. (See pl. 5, *B*.) The older chert was formed before the Mayes formation was laid down upon the Boone, for gravel composed of white chert, like that in the underlying Boone, is widespread in the basal beds of the Mayes. The younger chert was formed after the Mayes was deposited, for the Mayes is

extensively silicified with the jasperoid chert wherever associated with the ore deposits. The second silicification followed the shattering and brecciation of the older chert of the Boone and extended up into the Mayes formation, altering the limestone to chert and the sandstone to quartzite.

*Mayes formation.*—The Mayes formation unconformably overlies the Boone. It represents the basal formation of the Chester group and is overlain farther south by the Fayetteville shale and the Pitkin limestone. In the Joplin district it is called the Carterville formation. The Mayes formation in the Oklahoma part of the district has a thickness of 50 to 60 feet (15 to 18 meters). The formation consists of limestone, shale, and sandstone, usually with 10 to 30 feet (3 to 9 meters) of limestone in the lower portion, much shale with thin lenses of limestone in the middle, and 5 to 10 feet (1.5 to 3 meters) of fine sandstone at the top. Great lithologic variation characterizes the formation in both vertical and lateral directions.

The great differences in the thickness of the shale and limestone members of the Mayes, combined with the failure to recognize the general distribution of the Mayes overlying the Boone in the mining district, have probably contributed much to the common belief that there are many "sink holes" due to solution of the underlying Boone.

*Cherokee formation.*—The lower part of the Cherokee formation of Pennsylvanian age, is the surface formation in the western part of the mining region. The formation is mainly a black fissile shale having a maximum thickness of about 300 feet (91 meters) at Picher. Two sandstone members are recognized, one about 50 feet (15 meters) above the base, and the other at the top. There is a similar thickness of the formation in the low plain west of Blue Mound, where the shale forms a deep trough, the Miami syncline, as shown in Figure 20. At the base of the shale there is usually a thin conglomerate, containing chert gravel. Within the shale are thin seams of coal and some bitumen. The bitumen drips down into some of the mines from the overlying shale, but apparently there is no seepage until after the ground water is lowered in the mines. There appears to be no evidence of a decrease in thickness at the time of deposition of either the Cherokee or the Mayes formation along the present borders of their areas. The uniform thickness of members of these formations along the border seems to indicate that both once extended far beyond their present area and probably covered a large part of the Ozark Plateau.

*Igneous intrusives.*—Igneous rocks intrude the Carboniferous rocks of the surrounding region. Some 40 miles (64 kilometers) to the south of the mining district is the Spavinaw pegmatite

granite, the intrusion of which has arched the overlying Boone formation in the vicinity. About 70 miles (113 kilometers) northwest of the district occur the granite pegmatite intrusive and basic sills of the Rose Dome area, in Kansas. About 80 miles (129 kilometers) northeast of the district are intrusive rocks in Laclede County and Camden County, Missouri.

In May, 1930, granite was struck at a depth of 1,267 feet (386 meters) in drilling a water well at the Bird Dog mine, west of Picher, in the SE. ¼ sec. 13, T. 29 N., R. 22 E. The granite is interpreted by the writer as of intrusive origin because of its porphyritic pegmatitic texture, the marked silicification of the sandstone at the contact, and the absence of granitic material in the overlying sandstone. The pegmatitic granite apparently projects up through the lower part of the Cambro-Ordovician some 500 to 700 feet (152 to 213 meters) and has arched the

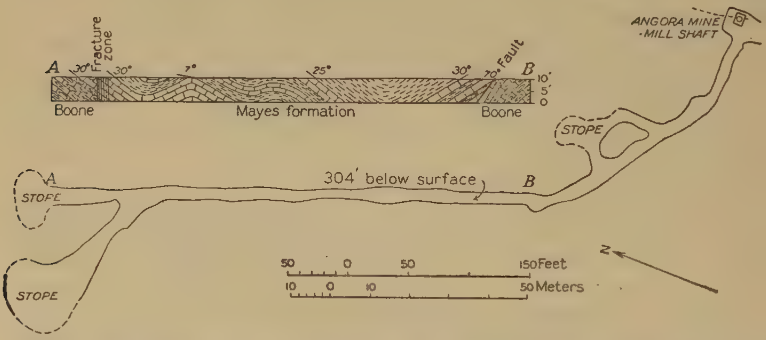


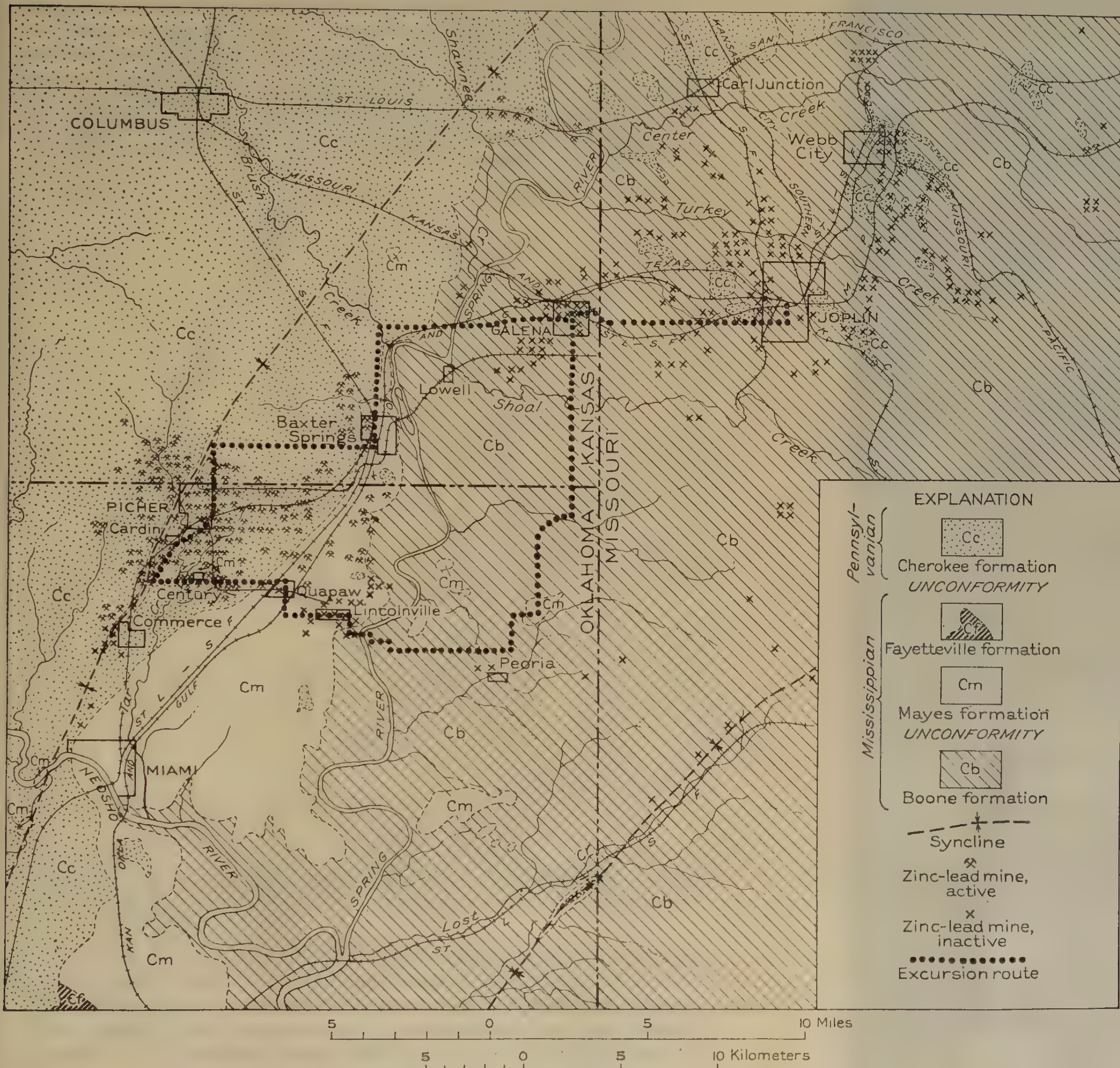

FIGURE 21.—Plan and section through Miami syncline along crosscut in Blue Goose-Angora mine, Picher district. (After Weidman, Samuel, Oklahoma Geol. Survey Bull. 56, 1932)

overlying strata adjacent to the Miami syncline, as indicated in Figure 20. It is the opinion of the writer that the intrusion of the granite also formed the adjoining syncline.

## STRUCTURE

*Folds.*—The Boone and overlying strata are characterized by undulating folds, in some places very gentle but elsewhere with dips as much as 20° to 30°. In places these folds are elongated and may be traced for a mile or so. In most places, however, the folding developed rather abrupt domes.

The most prominent fold, the Miami syncline, extends from the vicinity of Commerce N. 20° E. through the Picher field. (See pl. 7.) It is said to continue as far to the northeast as Lawton and Waco, and it has been traced southwest of Com-




GEOLOGIC MAP OF TRI-STATE REGION SHOWING LOCATION OF ZINC-LEAD MINES

Compiled by Samuel Weidman from geologic maps of the U. S. Geological Survey and the Missouri, Kansas, and Oklahoma State surveys.

merce for 20 to 25 miles (32 to 40 kilometers). In the Picher district the syncline has been referred to as the "Miami fault" or "Miami trough," and it has been described by some as a solution trough filled with slumped-in shale. However, the strata in the limbs of the syncline dip toward the axis, carrying the Boone, Mayes, and Cherokee formations from 50 to 200 feet (15 to 61 meters) below the normal level of the strata on either side of the fold. The syncline, though traceable for a


FIGURE 22.—Plan of S. S. & G. mine, Picher district, showing relation of major fractures to the axis of the syncline. (After Weidman, Samuel, Oklahoma Geol. Survey Bull. 56, 1932)

distance of 50 or 60 miles (80 to 96 kilometers) or more, is sharply folded only in certain sections of its course, as in the Picher district and 16 miles (26 kilometers) southwest of Miami.

The Seneca fault or syncline is essentially like the Miami syncline. In the small mines south of Seneca it is interpreted as an abrupt syncline carrying down the Cherokee shale over 100 feet (30 meters) below the adjacent Boone.

The Cow Creek anticline is a short and rather sharp fold in the Cherokee 5 miles (8 kilometers) west of Carl Junction. This anticline can be traced for a distance of about 2 miles (3.2 kilometers), trending northwest with dips of 35° to 40° on the east limb and 10° to 12° on the west limb.

*Faults.*—Faults with displacements of 30 to 40 feet (9 to 12 meters) or more are probably fairly common in association with the sharply folded sections of the Miami syncline.

*Fractures.*—Fractures are very abundant throughout the mining district, especially within the Boone formation. The fractures in the Boone are at least of two ages, some having been formed before and some after the overyling Mayes and Chero-


FIGURE 23.—Fracturing in Brewster mine, Picher district, illustrating variations in strike at a distance from the Miami syncline. (After P. W. George, in Weidman, Samuel, Oklahoma Geol. Survey Bull. 56, 1932)

kee were deposited. In this respect the two periods of fracturing are comparable to the two periods of silicification that have affected the rocks of the mining district. Both the trend and the dip of the fractures are variable. Within the sharply folded Miami syncline there is a strong tendency for the major fracture zones to trend diagonally across the axis of the fold, as shown in Figure 22. The diagonal position of the fractures with respect to the axis of the fold appears to indicate that both were formed by the same thrust, the axis being normal and the fractures approaching angles of 45° to the maximum

stress. Outside the syncline the fractures have a strong tendency to curve and usually do not continue in the same direction for more than 100 to 200 feet (30 to 61 meters), as illustrated in the Brewster mine. (See fig. 23.) However, northeast and northwest fractures are prevalent. Both upward and horizontal thrust probably developed the folding and fracturing.

*Breccia.*—Brecciation of the relatively brittle Boone chert by compressive movement has produced the most distinctive structural feature of the area, the ore-bearing rock being composed mainly of breccia. Folds, faults, and fractures are common throughout the surrounding region, but the breccia is mostly confined to the vicinity of ore deposits. The breccia is composed chiefly of angular fragments of the older, white chert, cemented by the later, dark-colored chert and dolomite and the ore minerals. The brecciated portions usually grade into surrounding fractured rock, but in some mines sharp nearly vertical walls mark the breccia boundary.

## ORE DEPOSITS

*Ore and gangue minerals.*—The principal ore minerals of economic interest are sphalerite and galena. Outside of the shale-covered portion of the region, where the ore horizon in the Boone lies above the ground-water level, the sphalerite has been much altered to smithsonite ($ZnCO_3$) and calamine ($H_2Zn_2SiO_5$), and the galena has been altered to a slight extent to cerusite ($PbCO_3$). The sulphate of lead, anglesite ($PbSO_4$), an alteration product of galena, was observed in several mines at a depth of 250 to 300 feet (76 to 91 meters), far below ground-water level. The anglesite is not associated with the secondary ore minerals formed in the zone of superficial alteration. Accessory sulphide minerals are marcasite and pyrite and less commonly chalcopyrite.

The common gangue minerals are chert, dolomite, and calcite. Aragonite, gypsum, quartz, and barite are less abundant.

The ore occurs as vein fillings in fractures, as replacement deposits in fracture walls, and as a constituent of the cement of the breccias. The typical ore breccia consists of angular fragments of the white chert cemented by dark or reddish chert, dolomite, which is generally pinkish, calcite, and the metalliferous minerals. (See pl. 5, *B*.)

*Shape of ore bodies.*—The ore bodies assume various shapes, more or less irregular, but according to their general form may be referred to as "flat runs," "vertical runs," and "pockets."

The flat runs in the Picher district range from 100 to 1,000 feet (30 to 305 meters) in width and from 5 to 30 feet (1.5 to 9

meters) in height. They lie roughly parallel to the stratification. The vertical runs range from 10 to 20 feet (3 to 6 meters) in width and often attain 100 to 150 feet (30 to 46 meters) in height. The vertical runs have steeply inclined or vertical walls and generally follow the nearly vertical fracture and fissure zones developed in the ore-bearing rock. The pockets are usually small bodies of ore-bearing rock, somewhat circular in shape.

In the older mining district about Joplin a common form of ore body was the "sheet ground" deposit, the ore occurring in thin sheets of almost horizontally bedded chert.

*Stratigraphic range.*—The ore-bearing zone is usually 50 to 100 feet (15 to 30 meters) in thickness and consists of highly silicified and dolomitized Boone limestone, within which the ore deposits have a variable distribution. Generally it occurs in the lower part of the upper half of the formation, about 100 to 150 feet (30 to 46 meters) below the top. A notable exception occurs where the ore zone extends through the Miami syncline in the Picher district, as shown in Figure 20. Where the Boone and overlying Mayes and Cherokee formations are folded downward some 50 to 200 feet (15 to 61 meters) below their normal level in the syncline, the ore zone maintains its approximate level and rises to a higher stratigraphic horizon, so that the ore deposits extend up into the upper beds of the Boone and into the silicified limestone and "sandspar" and even the shale of the overlying Mayes formation.

*Relative richness of mines.*—The ore bodies are larger and richer beneath the shale in the Picher district than in the area about Joplin. At present it is impossible to obtain records of production of the mines in the Joplin district, and therefore only estimates based on the best information now available can be given. In the new district about Picher, however, complete records of production are available from the companies now operating.

*Production of important mines in the Joplin, Galena, and Picher districts to 1928*

[From Oklahoma Geol. Survey Bull. 56, 1932]

| Mine | Area leased (acres) | Estimated area mined (acres) | Period of operation | Concentrates produced (tons) | | | |
|---|---|---|---|---|---|---|---|
| | | | | Lead | Zinc | Per acre leased | Per acre mined |
| Joplin district: | | | | | | | |
| American | 280 | 140 | 1902–1919 | 53,352 | 126,681 | 643 | 1,286 |
| Lincoln | 160 | 40 | ---------- | Some. | 35,280 | 220 | 880 |
| Wilson | 80 | 7 | ---------- | 1,350 | 12,250 | 170 | 1,800 |
| Galena district: | | | | | | | |
| South Side | 80 | 60 | 1877–1928 | 45,071 | 136,897 | 2,274 | 3,032 |
| Picher district: | | | | | | | |
| Beaver | 40 | 9 | 1916–1928 | 19,768 | 51,890 | 1,791 | 7,963 |
| Beck | 80 | 16 | 1919–1928 | 4,549 | 88,840 | 1,167 | 5,836 |
| Brewster | 80 | 16 | 1919–1928 | 14,957 | 112,098 | 1,588 | 7,941 |
| Goodwin | 50 | 18 | 1917–1928 | 5,536 | 71,016 | 1,531 | 4,253 |
| Oklahoma-Woodchuck | 40 | 10 | 1917–1928 | 20,052 | 79,610 | 2,441 | 9,966 |
| Velie-Lion | 80 | 16 | 1917–1928 | 18,153 | 70,299 | 1,106 | 5,529 |
| Barr (Kansas) | 60 | 14 | 1917–1928 | 26,021 | 100,504 | 2,108 | 9,037 |
| Webber (Kansas) | 60 | 14 | 1919–1928 | 21,962 | 100,228 | 2,036 | 8,733 |

The South Side mine, at Galena, has the unusual mining record of being a continuous producer for more than 50 years. Probably about one-fourth of its production came from small deposits, or "diggings," along mainly lead ore crevices above ground-water level, in the upper part of the ore-bearing zone, a type of deposit commonly mined in the Joplin district but impracticable of development in the deeper-lying ore deposits beneath the shale of the Picher district. The notable production from shallow depth in the South Side mine seems to indicate that considerable ore in small deposits in the upper part of the ore zone will probably be left in the ground when the deeper mines in the Picher district are abandoned.

The mines in the Picher district listed in the table were active producers in 1928 and will probably yield from 10 to 50 per cent more than that reported, and hence the difference in size and richness of the ore bodies in the Picher district as compared with those about Joplin will eventually be greater than that indicated in the table.

*Origin.*—According to two of the three theories of origin generally advanced, the metallic contents of the ore bodies were originally sparsely distributed in the sedimentary rocks of the Ozark region, and their concentration into workable ore deposits was effected by cold meteoric waters. According to one theory the waters were descending ground waters; according to the other they were ascending artesian waters.

Winslow, Buckley, and Buehler have been the leading advocates of the theory that postulates descending ground waters. They believe that the process of ore deposition has been one of enrichment, below the level of ground water, of metals leached out of overlying rocks, above the level of ground water, by converging downward-circulating waters.

Van Hise, Bain, Smith, and Siebenthal have championed the theory that postulates artesian circulation. Siebenthal in particular worked out a very complete case for the theory in this district. He showed that the district lies at the outlet of an extensive artesian circulation down the flanks of the Ozark uplift and is especially favorably situated with respect to the emergence of the circulation from the Cambrian and Ordovician dolomites. He found that the lead-zinc ratio of these rocks, of the artesian waters in them, and of the ore deposits was the same. The dolomitization that accompanied ore deposition he regarded as further evidence of the important part played by the Cambrian and Ordovician waters.

The third theory holds that the ores were deposited by ascending thermal waters or vapors emanating from a magmatic source. Pirsson, Spurr, W. H. Emmons, Weidman, Fowler, and Lyden

have presented evidence and arguments in support of this view. These authors have stressed the structural relations of the ore bodies and the localization of the ores in places where the Boone formation has undergone deformation which has caused shearing and shattering. In such places the beds have become chertified, brecciated, and mineralized. Emmons has tied up the distribution of the metals of the Ozark region with the zonal distribution to be expected from ascending thermal solutions.

The great weakness of the magmatic theory has been the absence of known intrusive rocks in the proximity of the deposits. Weidman has emphasized recent evidence of the existence of such intrusives as the granite dike, which he estimates to have a width of 500 to 1,000 feet (152 to 305 meters) and which arched the strata adjacent to the Miami syncline, the Rose dome of Woodson County, Kansas, 75 miles (121 kilometers) northwest of the district, and the Spavinaw granite, 40 miles (64 kilometers) to the south. Extensive silicification of the intruded rocks accompanied these intrusions. They are regarded as evidence of widespread igneous activity that affected the rocks of the district.

The level at which the ores were deposited is considerably above the top of the granite intrusion adjoining the Miami syncline. At the Bird Dog mine there is an interval of 1,000 feet (305 meters) of barren rock between them. The vapors emanating from the magma may have been too high in temperature and pressure for crystallization. The widespread lateral zone in which the ore deposits are distributed represents a common level at which the ascending solutions attained physical conditions favorable to ore deposition. This level is generally from 100 to 200 feet (30 to 61 meters) below the top of the Boone formation but extends higher stratigraphically where the strata have been depressed, as in the Miami syncline.

The Miami syncline is post-Pennsylvanian, and as similar folding includes Permian strata farther west, its age is probably Mesozoic. At that time the Ozark region was covered with 1,000 to 3,000 feet (305 to 914 meters) of Pennsylvanian strata, which have since been eroded. Folding, fracturing, brecciation, and ore deposition are believed to have had a common origin related to the igneous intrusions. They are believed to have been controlled by conditions that no longer exist and are consequently inexplicable by the theories that appeal to meteoric waters.

*Prospecting.*—Prospecting is carried out by churn drilling 6-inch (15-centimeter) holes. A sample of the cuttings for every 5 feet (1.5 meters) of barren formation and 2½ feet (0.75 meter) of mineralized rock is saved to constitute a log of the hole. In prospecting new ground holes are drilled at intervals of 200 to 300 feet (61 to 91 meters). When ore is located, closer holes are

drilled to determine the trend and width of the ore body. Frequently as many as 250 holes are drilled on a 40-acre (16-hectare) tract, and over 20,000 holes have been drilled in the 20 square miles (52 square kilometers) comprising the Picher field. The depths of the holes range from 100 to 400 feet (30 to 122 meters). Drilling is generally done by contract at about $1 a foot.

*Mining.*—After an ore body is located and outlined by drilling, one or more shafts are sunk and connected with air drifts to afford natural ventilation. The shafts are generally located in the ore body, so that mining begins at once.

The mining method used almost exclusively is the cutting of open stopes with irregular pillars. Ore has been mined from the rock immediately under the subsoil down to a depth of 400 feet (122 meters). Ore faces vary in height from 8 feet (2.4 meters) to over 100 feet (30 meters). It is estimated that about 15 per cent of the ore is originally left as pillars.

*Milling.*—The district is one of the few in which jigging is still extensively used. The Harz jig is the preferred type. Since 1923 flotation has been employed on a large scale and has in many mills led to the abandonment of tables.

About 10 years ago the average mill capacity was 25 to 30 tons (23 to 27 metric tons) an hour. Recently there has been a tendency to increase the capacity, and now 50 tons (45 metric tons) an hour is common, and some mills have a capacity of 100 tons (91 metric tons) or more an hour.

The ores from the Oklahoma-Kansas portion of the district have averaged 5.5 per cent of zinc and 1 per cent of lead. The average annual output of ore has been about 10,000,000 tons (9,072,000 metric tons). Since 1927 remilling of old tailings has been carried on at the rate of about 3,000,000 tons (2,722,000 metric tons) a year. These tailings have yielded 1.5 per cent of zinc and 0.01 per cent of lead.

## TYPICAL MINES NEAR PICHER

*Blue Goose-Angora mine.*—The Blue Goose-Angora mine of the Commerce Mining & Royalty Co., in the Picher district, includes three 80-acre (32-hectare) leases.

The ore occurs from 290 to 313 feet (88 to 95 meters) below the surface. The height of stopes ranges from 35 to 80 feet (11 to 24 meters), and the width from 25 to 90 feet (7.6 to 27 meters). The ore-bearing rock is much broken jasperoid breccia, containing many small openings partly filled with ore mineral and calcite. Galena incrusted with yellowish anglesite occurs on the 290-foot (88-meter) level, under 130 to 150 feet (40 to 46 meters) of shale and far below ground-water level.

The Miami syncline extends northeastward across the Angora lease, and the central part of the trough contains a thickness of 250 to 300 feet (76 to 91 meters) of shale. A crosscut on the 304-foot (93-meter) level, through the bottom of the trough (fig. 21), extends through shale of the Mayes formation. On both limbs of the syncline, at the contact of the Mayes and Boone, there is evidence of pronounced deformation—a fault of 30 to 40 feet (9 to 12 meters) displacement on the southeast limb and a zone of fracture 5 to 10 feet (1.5 to 3 meters) wide on the northwest limb.

*Brewster mine.*—The Brewster mine of the Federal Mining & Smelting Co. is operated from four shafts. The mine levels range from 211 feet (64 meters) below the surface in the eastern part of the mine to 231 feet (70 meters) in the western part. The ore body shows a slight dip to the west, in conformity with the regional westward dip of the strata. The width of the stopes is usually from 50 to 100 feet (15 to 30 meters), and their height is 20 to 60 feet (6 to 18 meters) in the eastern part and 10 to 30 feet (3 to 9 meters) in the western part. (See fig. 23.)

Two types of ore-bearing ground may be recognized on the same level. In the western part of the mine the ground is relatively "tight"; in the eastern part it is more "open" and "bouldery." The boundary between the tight and the open ground is relatively sharply defined by a much fractured zone trending north. Most of the prominent fractures trend slightly west of north, and in this direction the stopes are relatively high and narrow. In contrast the stopes trending nearly due east are low and wide.

Anglesite altered from galena occurs in a flat seam of flint rock having a lateral extension of 100 to 150 feet (30 to 46 meters) in the upper part of a pillar. The pyromorphite is not associated with oxidized ores of either sphalerite or galena.

A thickness of 30 to 40 feet (9 to 12 meters) of shale overlies the eastern part of the lease, and from 50 to 60 feet (15 to 18 meters) the western part. Brown and gray limestone of the Mayes formation is 20 to 30 feet (6 to 9 meters) thick. The oolite horizon is at a depth of 170 to 180 feet (52 to 55 meters), about 125 feet (38 meters) below the top of the Boone, in the middle part of the ore-bearing zone.

*Netta mine.*—In the Netta mine of the Eagle Picher Lead Co. the ore occurs in flat runs at three fairly well defined levels—200, 235 to 245, and 270 feet (61, 72 to 75, and 82 meters) below the surface. The height of the mine stopes ranges from 10 to 25 feet (3 to 7.6 meters) and their width from 50 to 500 feet (15 to 152 meters) or more. The ore follows the bedding and

also the well-defined nearly vertical fractures trending in northeast and northwest directions.

The ore is mainly typical jasperoid breccia. The less broken formation is crossed with vertical fractures or fissures filled with calcite and galena. In places vertical fissures are slickensided, showing displacement of several inches. Aragonite occurs as a filling in small cavities on the lowest mine level, where it is developed upon the common form of "dog tooth" calcite, on white flint, and on sphalerite.

Several caves have been encountered in the Netta mine. One of the largest is about 100 feet (30 meters) in lateral extension and 4 feet (1.2 meters) in greatest height at the center, narrowing down to less than an inch (2 centimeters) at the border. It has a domed ceiling and a rough, uneven flat floor, and both ceiling and floor are covered with large calcite crystals. Although this cave adjoined a rich ore body in fractured brecciated rock it was entirely barren of ore. A smaller cave in another part of the mine has the ceiling covered with small crystals of galena and calcite.

The thickness of overlying shale at the Netta mine ranges from 70 to 120 feet (21 to 37 meters), and the silicified ore-bearing zone in which the caves occur is 100 to 125 feet (30 to 38 meters) below the top of the Boone, more than 200 feet (61 meters) below the general level of ground water.

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# THE ARKANSAS BAUXITE DEPOSITS

By George C. Branner

ABSTRACT

The Arkansas bauxite deposits, which are confined to Pulaski and Saline Counties, are the residual products of the alteration of nephelite syenite. The bauxite grades downward to a porous kaolin, which in turn grades into syenite. Except for exposures of syenite and bauxite, the surface formations in the mining districts consist of unconsolidated Tertiary sands and clays. Mining is carried on mainly by underground methods, although stripping and open-pit mining are also used.

Arkansas has been first in the production of bauxite in the United States since 1902. In 1930 Arkansas produced 315,273 long tons (320,333 metric tons), which was 95.3 per cent of the bauxite produced in the United States, or 42.5 per cent of the sum of the imports and production in the United States. The known reserves are probably sufficient to last for many years. Future prospecting may result in the discovery of larger reserves than those now known.

## INTRODUCTION

*Location.*—The bauxite region of central Arkansas is divided into two mining districts—(1) the Fourche Mountain district, which is immediately south and southeast of Little Rock, in Pulaski County; (2) the district around the town of Bauxite, which is about 5 miles (8 kilometers) east of Benton in the eastern part of Saline County. (See fig. 24.) These two mining districts are about 14 miles (23 kilometers) apart and are separated by territory which up to the present time has produced no commercial ore.

The Bauxite district, the larger and more productive of the two, will be visited. It is 20 miles (32 kilometers) by highway southwest of Little Rock.

*Topography and culture.*—The surface of the bauxite region is made up of low hills of unconsolidated clay, sand, and gravel and projecting masses of nephelite syenite. The tops of a few hills in the region are slightly more than 500 feet (152 meters) above sea level. The amount of relief, however, is usually less than 150 feet (46 meters) except at Fourche Mountain, south of Little Rock, which has a relief of 250 feet (76 meters).

The soil of the region is mostly sandy and not especially fertile. The region is thinly populated. It is timbered principally with pine and a little gum and oak.

## GEOLOGY

The bauxite mining areas lie within and close to the border of the Gulf Coastal Plain (about 4½ miles (7.2 kilometers) southeast of the border in Pulaski County and 5½ miles (8.8 kilometers) in Saline County). This "shore line" marks the contact between the highly folded Paleozoic beds of the Ouachita

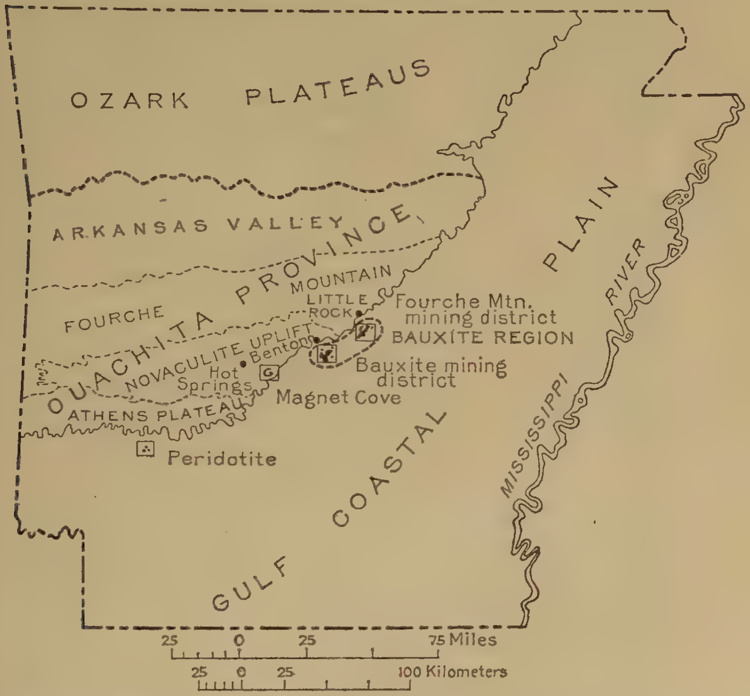


FIGURE 24.—Map showing location of bauxite region and Magnet Cove, Arkansas, with reference to major geomorphic subdivisions

province and the nearly flat-lying Tertiary and Quaternary beds of the Gulf Coastal Plain.

The unconsolidated sands and clays of the bauxite region are of Tertiary age and unconformably overlap the Paleozoic strata which were peneplaned and submerged beneath encroaching seas. The general plane of the Tertiary-Paleozoic contact in Pulaski and Saline Counties slopes to the southeast about 105 feet to the mile (20 meters to the kilometer). This tilt is the result of a downwarping of the Mississippi embayment. (See fig. 25.)

A batholith of nephelite syenite was intruded into the folded Paleozoic beds, probably during Upper Cretaceous time. Dikes of darker augitic rock, classified by Williams (2)[1] as fourchite, ouachitite, and monchiquite, are associated with the syenite. Portions of this batholith were later exposed by erosion. The bauxite was formed on the exposed syenite surface as a residual product. Eventually these surfaces were covered by Tertiary sediments. Later, as the unconsolidated sediments were eroded from the elevated Tertiary plain, relatively small areas of syenite and bauxite were uncovered. Mead's theory (5) is as follows:

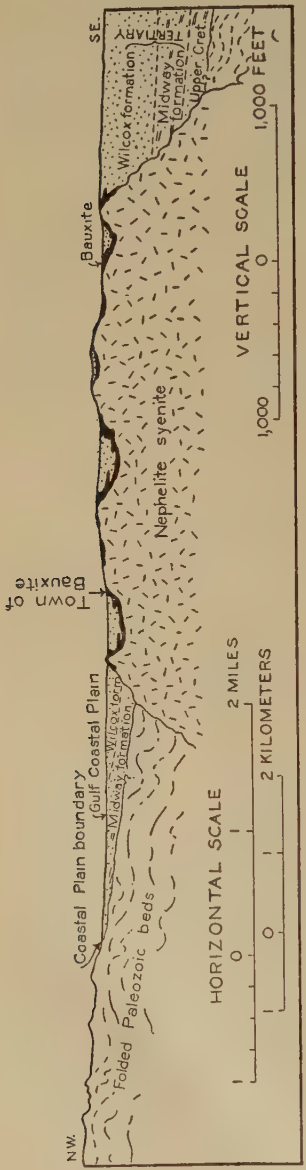


FIGURE 25.—Section through Bauxite mining district

> Large masses of nephelite syenite were intruded into folded Paleozoic rocks and subsequently exposed at the surface by erosion. The bauxite deposits were developed on the undulating surface of the syenite by weathering and suffered considerable contemporaneous erosion by streams. The entire area was then covered by terrestrial sediments of probable Tertiary age consisting of clays, sands, and gravels with lenses of lignitic material. The syenite areas, being more resistant to erosion, stood in relief above the surrounding areas of softer rocks on the Tertiary land surface, and the bauxite deposits suffered erosion contemporaneous with the deposition of the lower Tertiary sediments. This resulted in the transportation of bauxite and its interstratification with sands and gravels around the border of the syenite area and in topographic depressions within it. Recent erosion has cut through the Tertiary sediments, exposing the underlying igneous rocks and the bauxite deposits.

Recent geophysical exploration in the bauxite region by Stearn (9) indicates the presence of an igneous province in central Arkansas about 400 square miles (1,036 square kilometers) in ex-

[1] Numbers in parentheses refer to bibliography, p. 102.

tent, of which the exposed areas of nephelite syenite are a part. Bauxite bodies may be associated with portions of the buried igneous rock which may be nephelite syenite and which may have been exposed during pre-Tertiary time.

## ORE DEPOSITS

[Principally from Mead (5)]

In general terms, there are five steps in the formation of bauxite from the nephelite syenite. These are (1) unaltered nephelite syenite; (2) partly kaolinized syenite, nephelite partly removed;

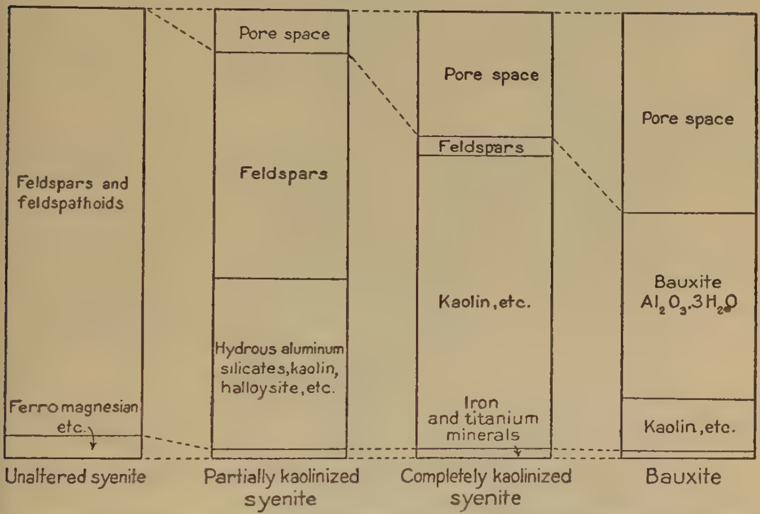


FIGURE 26.—Diagram showing, in terms of volume, the gradation from syenite to bauxite. The columns represent a series of samples from a single locality. (After Mead)

(3) completely kaolinized syenite, nephelite more completely removed; (4) bauxite, nonmerchantable ore (high in silica); (5) bauxite, merchantable ore (low in silica).

There is an unbroken sequence of chemical events in the formation of bauxite from nephelite syenite. Figure 26 shows the volumetric relations of the constituents of the bauxite to those of the kaolinized syenite and the unaltered syenite.

Two classes of ore are found—ore in place and transported ore.

Three types of bauxite are found in place. These are

(*a*) Pisolitic or "oolitic" ore. This is the most prevalent of the three types. It is more characteristic of the upper portions of the ore bodies and is usually found above the "granitic" type,

into which it grades. The pisolites usually increase in size from the bottom to the top of ore of this type. This ore consists principally of amorphous aluminum trihydrate ($Al_2O_3.3H_2O$) which has altered from the crystalline form (gibbsite).

(*b*) "Granitic" or sponge ore. In this type the texture of the syenite is preserved. It is more characteristic of the lower portions of the ore bodies and is usually found above the completely kaolinized syenite, into which it grades. It consists

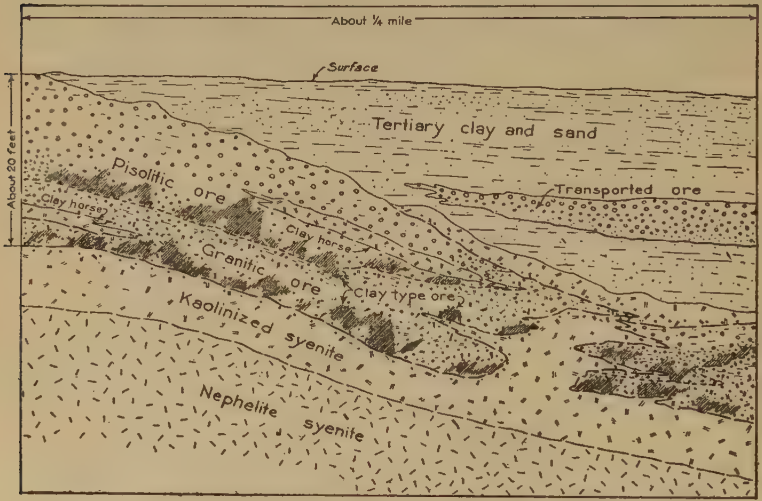


Figure 27.—Section showing the relation between the syenite, bauxite, and Tertiary beds

principally of crystalline aluminum trihydrate ($Al_2O_3.3H_2O$) or gibbsite.

(*c*) Amorphous or "clay" ore. This is the least abundant of the three. It has much the appearance of kaolin and characteristically grades into both the pisolitic and granitic types of ore.

Transported ore may be any combination of the above described types of bauxite, as it is derived from one or more of the three types.

A section of a characteristic ore body is shown in Figure 27.

BAUXITE ORE BODY STRIPPED BY PICK AND SHOVEL AND PARTLY CLEANED

*A.* NEPHELITE SYENITE BOULDERS SHOWING ALTERATION TO KAOLINIZED SYENITE AND BAUXITE

*B.* CONTACT BETWEEN TERTIARY SANDS AND CLAYS AND BAUXITE BODY, ARKANSAS BAUXITE DISTRICT

## MINING METHODS

[Principally from information furnished by the Republic Mining & Manufacturing Co.]

From 1924 to 1930 about 40 per cent of the ore mined in Arkansas was mined by open-cut methods and about 60 per cent by underground methods, mainly by retreating caving. Nearly all the exposed ore in Arkansas has now been exhausted, and only ore that lies under an overburden of unconsolidated sand, clay, and gravel is being mined. Determining factors governing the choice of mining methods are depth of overburden, thickness and quality of ore, shape and inclination of ore body, drainage, and proximity to suitable dumping ground for waste. (See pl. 8.)

Sections of overburden and bauxite at four open pits in the Bauxite district are shown below.

*Section at Globe mine, Superior Bauxite Co.*

[Wheel-scraper stripping and hand loading]

| | Feet | Meters |
|---|---|---|
| Gravel | 8 | 2.4 |
| Sand and clay | 4 | 1.2 |
| Lignite | 4 | 1.2 |
| Black clay | 6 | 1.8 |
| Bauxite | 12 | 3.6 |

*Section at mine of Republic Mining & Manufacturing Co.*

[Shovel stripping and hand and shovel mining]

| | Feet | Meters |
|---|---|---|
| Gravel | 13 | 3.9 |
| Sand and clay | 4 | 1.2 |
| Lignite | 6 | 1.8 |
| Black clay | 4 | 1.2 |
| Hard cap | 2 | .6 |
| Bauxite | 14 | 4.2 |

*Section at Section 14 mine of Republic Mining & Manufacturing Co.*

[Hand and shovel stripping and mining]

| | Feet | Meters |
|---|---|---|
| Sand and clay | 2–40 | 0.6–12 |
| Bauxite | 6–20 | 1.8– 6 |

*Sections at Section 14 mine of Republic Mining & Manufacturing Co.*

[Shovel stripping and hand loading]

| | Feet | Meters | Feet | Meters |
|---|---|---|---|---|
| Gravel | 10 | 3 | 6 | 1.8 |
| Sand and clay | 24 | 7.3 | 20 | 6 |
| Hard bauxite | 2 | .6 | 1 | .3 |
| Bauxite | 9 | 2.7 | 8 | 2.4 |

According to Cash and Von Bernewitz (7), ore mined in the Bauxite district usually lies under more than 20 feet (6 meters), in some places more than 100 feet (30 meters) of sand and clay

overburden. The maximum depth of stripping which has been attempted is 80 feet (24 meters), but usually the depth does not exceed 45 feet (14 meters). The ore bodies average about 11½ feet (3.5 meters) in thickness and dip at a low angle. The maximum thickness is about 35 feet (11 meters). In the Fourche Mountain district the maximum thickness is 62 feet (19 meters). In the Bauxite district the strip area is irregular, but a continuous working face 2,000 feet (610 meters) in length is possible. The economic limit of stripping for high-grade ore is about 3 cubic yards (2.3 cubic meters) of overburden to 1 cubic yard (0.76 cubic meter) of bauxite.

In undertaking to mine property on which outcrops or other evidence indicate the presence of deposits, the usual procedure is as follows:

1. Holes are drilled at 200-foot (61-meter) intervals. Ore is analyzed every 2 feet (0.6 meter). Drilling usually costs about 80 cents a foot ($2.62 a meter), and holes average 100 feet (30 meters) in depth. From 2 to 12 chemical analyses are required for each hole, at $1 a sample. This first step costs from $125 to $150 an acre ($309 to $371 a hectare).

2. If the first drilling results are satisfactory, a second series of holes are drilled at 50 to 100 foot (15 to 30 meter) intervals. A subsurface map of the ore showing its quality is prepared. This step costs from $375 to $500 an acre ($926 to $1,235 a hectare).

If open-pit mining is decided upon, the procedure is as follows:

1. The land is cleared of timber.

2. Railroad tracks are laid, and 2½-yard (1.91 cubic meters) steam shovels remove the heavy overburden, which is loaded into automatic side-dump waste cars and hauled in train loads to the dump.

3. Small power shovels of the caterpillar type or tractor or mule drawn scrapers remove the waste remaining in hollows and valleys.

4. The top crust of the bauxite is removed by heavy road machines hauled by 10-ton (9 metric tons) caterpillar tractors.

5. Clay pockets and remaining overburden are removed by pick and shovel.

6. The surface of the ore is swept with steel brooms. (The contract cost of complete stripping was 30 cents a cubic yard (39 cents a cubic meter) in 1929, according to Cash and Von Bernewitz (7).)

7. Mining faces are laid out. The ore is loosely consolidated but is usually too hard to be mined without being broken by blasting.

8. If blasting is necessary holes equally spaced are put down 6 feet (1.8 meters) with small air drills and the remaining necessary depth by hand drilling.

9. Ore is blasted, low-strength dynamite being employed.

10. After blasting, boulders are broken.

11. Broken bauxite is loaded into 1¾-ton wooden end-dump cars, either by hand or power shovel.

12. Loaded cars are hauled to the milling plant in trains of 10 to 25 cars by steam locomotives. The track is 36-inch (0.9 meter) gage, with 60-pound (27-kilogram) rails. Each car is tagged with an analysis card which shows the quality of the ore.

In underground mining the procedure is as follows:

1. The ore body is reached at several favorable points simultaneously by shaft, slope, or adit—possibly by all three.

2. Main tunnels, airways, and crosscuts are started.

3. When work has progressed far enough to establish main haulageways, drainageways, and airways, mining and extraction of ore is started by drilling auxiliary side tunnels, drifts, etc. The physical characteristics of the ore determine the mining method used—room and pillar, breast stope and pillar, overhand or underhand stopes, vault or open stopes, etc. As the bauxite has a tendency to harden on exposure to air, very little timbering is required.

4. Ore is loaded into mine cars and hauled to the mine entrance by battery locomotives.

5. Pillars are robbed and the roof caved behind the workings.

## PREPARATION OF ORE

Cars having a capacity of 1¾ tons deliver the ore to a conveyor, which discharges it into crushers. These reduce the material to lump not exceeding 4 inches (10 centimeters) in diameter. It is then carried by conveyor to either a rotary calcining or a rotary drying kiln. Natural gas is used to dry and calcine. Calcined ore is heated to redness (about 2,400° F. or 1,315° C.) and is cooled in a water-jacketed cylinder before being conveyed to loading bins. Calcining reduces the combined water content to 2 per cent or less. Dried ore is heated to 200° to 250° F. (93° to 121° C.), and the free water content is reduced to 2 per cent or less.

Crushed, dried, and calcined ore streams are sampled at regular intervals and analyzed in order to check the quality. The railroad cars used are standard box or steel hopper-bottom cars with roofs.

The average requirements, in percentages, for dried commercial ore are as follows:

| | Metallic grade | Abrasive grade | Chemical grade |
|---|---|---|---|
| $Al_2O_3$ | 56–61 | 54–58+ | 54+ |
| $SiO_2$ | 0–6 | 0–4 | Not important. |
| $Fe_2O_3$ | 0–10 | 0–5 | 0–5 |
| $TiO_2$ | 0–4 | 0–4 | 2½–3¼ |
| $H_2O$ | 22–27 | 29–31 | 30–31 |

## PRODUCTION

Bauxite was first identified in Pulaski County, Arkansas, in June, 1888, by Dr. John C. Branner, and part of its surface distribution in Pulaski and Saline Counties was described in print on January 8, 1891.

The first recorded production of bauxite was made in 1899, and from that time to 1930, inclusive, 6,799,224 long tons (6,908,351 metric tons), valued at $38,895,257, was produced. This was 87.8 per cent of the total production of the United States during this period. Approximately 8.7 per cent of this amount was mined in Pulaski County and 91.3 per cent in Saline County. Two subsidiaries of the Aluminum Co. of America—the American Bauxite Co. and the Republic Mining & Manufacturing Co. (now combined under the name of the latter)—have produced most of the ore.

In 1930 the amount of bauxite mined in Arkansas was 315,273 long tons (320,333 metric tons), which was 95.3 per cent of the total amount produced in the entire United States (330,612 long tons, or 335,918 metric tons), and 42.5 per cent of the sum of the imports and production in the United States (740,299 long tons, or 752,180 metric tons).

According to the United States Bureau of Mines, the percentages of the bauxite mined in this country during 1930 sold to the manufacturers of bauxite products were as follows:

| | |
|---|---|
| Aluminum | 54.4 |
| Chemical products | 20.5 |
| Abrasives | 24.8 |
| Refractory products and cement | .3 |
| | 100.0 |

The companies producing Arkansas bauxite in July, 1931, were, in Saline County, the Republic Mining & Manufacturing

Co. and the Kalbfleisch Corporation (Inc.), both at Bauxite; and in Pulaski County the Republic Mining & Manufacturing Co. and Dixie Bauxite Co., both at Sweet Home.

The production of bauxite in Arkansas from 1899 to 1930 according to the United States Bureau of Mines and the Arkansas State severance tax records is shown in Figure 28.

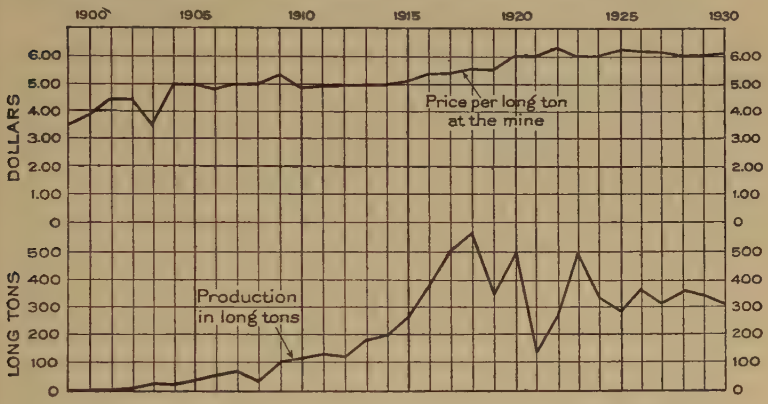


FIGURE 28.—Production of bauxite in Arkansas, 1899–1930

## RESERVES

No detailed estimates of the reserves of merchantable ore in either Saline or Pulaski County have been made public. Stearn (9) concludes that the undiscovered bauxite reserves of these counties may be much larger than was before thought probable and that the territory in which exploration can logically take place includes an area of about 165 square miles (427 square kilometers). He further states that the proportion of this area actually underlain by bauxite is unpredictable, but it is undoubtedly small.

It is estimated that since 1899 about 6,207,700 long tons (6,307,333 metric tons) of bauxite has been removed from Saline County and about 591,500 long tons (600,993 metric tons) from Pulaski County, an approximate total of 6,799,200 tons (6,908,327 metric tons). The known reserves are doubtless sufficient to last for many years.

The life of the Arkansas bauxite reserves is dependent on the rate of production, which is in turn, to a considerable degree, influenced by the imports, which come principally from British and Dutch Guiana.

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## ITINERARY

Upon arrival at the office of the superintendent of the Republic Mining & Manufacturing Co., walk east through stone gate. Turn right on east side of buildings and walk to unloading platform and board observation cars.

Stop 1. In cut. Note bauxite on both sides and "granite" boulders showing gradation from nephelite syenite to kaolinized syenite and bauxite. (See pl. 9, *A*.)

Stop 2. Lantz mine on left. Note character of stripping operations. About 600,000 cubic yards (459,000 cubic meters) of overburden was removed from this area and about 150,000 long tons (152,400 metric tons) of ore taken out to 1931. About 10 acres (4 hectares) has been mined over an area 800 by 1,400 feet (244 by 427 meters). The thickness of the ore ranged from 0 to 18 feet (5.5 meters) with an average of 14 feet (4.3 meters). From 0 to 40 feet (12 meters) of kaolinized syenite lies between the base of the bauxite and the top of the syenite.

Track curves to right. Shop on left takes care of minor equipment repairs. Major repairs are sent to main shop at plant. Water drainage canal on left drains 4 miles (6.4 kilometers) to east. This is part of the bauxite mine drainage system, which is 10 to 30 feet (3 to 9 meters) in depth.

Stop 3. Stripping operations on right at the Area C and Area B mines. Tertiary beds overlie bauxite. Irregular contact at top of bauxite with boulders of detrital or conglomeratic ore. Lignite overlies bauxite. Bauxite dips 16° W. Ore averages 16 feet (4.8 meters) in thickness, with 20 feet (6 meters) of sand and clay overburden.

On leaving Area B mine, straight contact is seen on right between top of ore and Tertiary overburden. Track curves to right. Note syenite on left near small house. Syenite hill on right.

Stop 4. Maude mine. Principally "granitic" or sponge ore; also pisolitic and amorphous types. Top of bauxite is highly irregular eroded surface. Lignite appears only in the lower portion of the mine. Approximately 3 acres (1.2 hectares) of ore is exposed here.

Return to Area B mine. Tracks branch to right, to Davis portal. At right of entrance to portal lignitic beds overlie ore, and next to track is 4 to 5 feet (1.2 to 1.5 meters) of kaolinized syenite which grades upward into bauxite. Ore at Davis portal is of "granitic" type and about 16 feet (4.9 meters) thick. Ore slopes about 13°.

Train proceeds underground with a stop at syenite boulders and a stop to note stope method of mining. These underground workings have a total length of about 20 miles (32 kilometers). There is from 6 to 8 miles (9.6 to 12.9 kilometers) of open tunnel.

Return to plant, where ore cars are unloaded. The cars are tagged to indicate chemical character of ore. Here will be seen experimental washing equipment for mechanical removal of silica and the drying and calcining section. The installation consists of two 120-foot (37-meter) and seven 60-foot (18-meter) dryers and one 150-foot (46-meter) and three 60-foot (18-meter) calciners. Natural gas is used for fuel.

# MAGNET COVE, ARKANSAS

By K. K. Landes, Bryan Parks, and Vernon E. Scheid

ABSTRACT

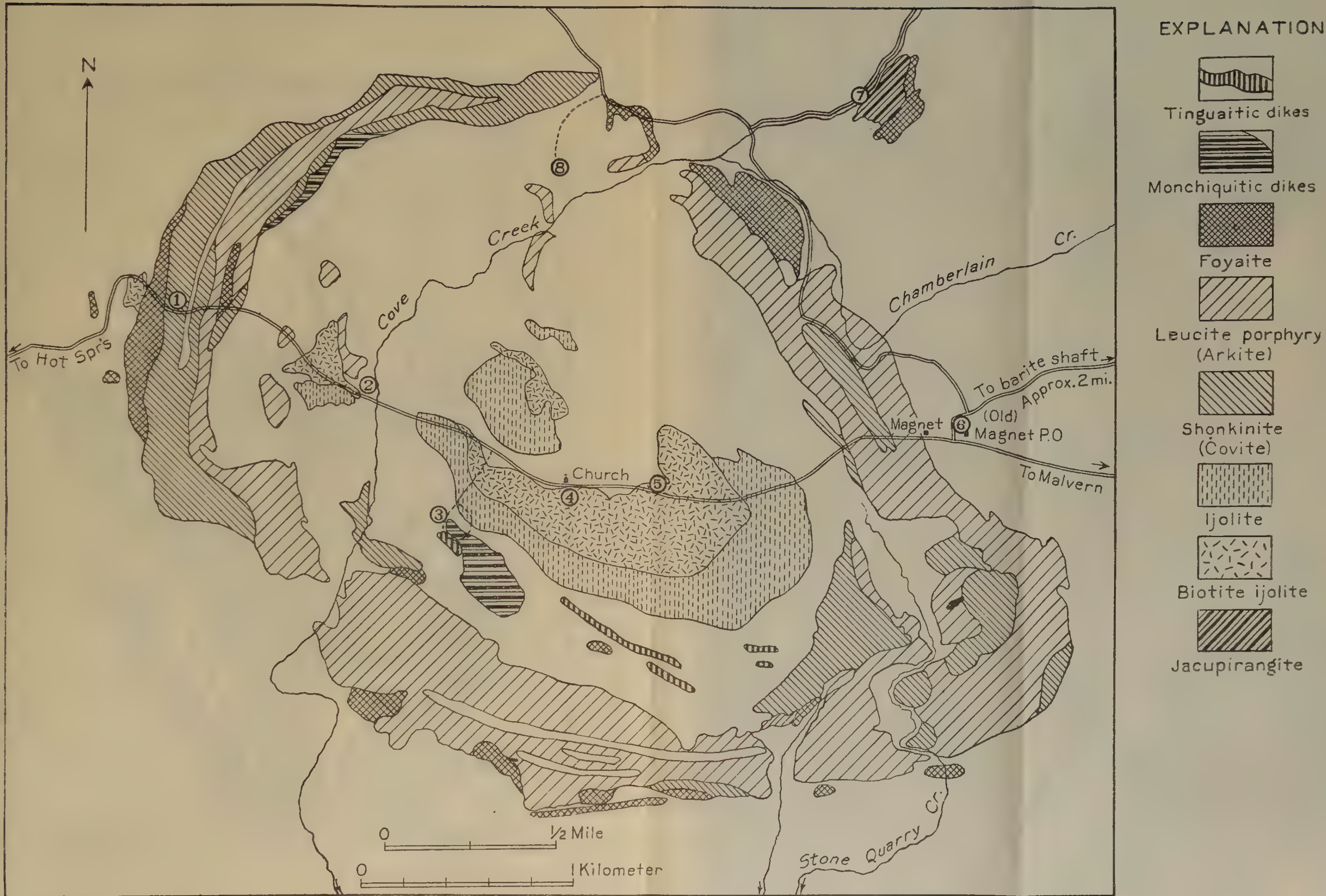
The Magnet Cove intrusive complex is elliptical in plan, with a major diameter of about 15,000 feet (4,572 meters), a minor diameter of about 10,000 feet (3,048 meters), and an area of about 5.1 square miles (13.2 square kilometers). The country rock comprises novaculite, sandstone, and shale of Upper Devonian and early Mississippian age and sandstones of Silurian age. In the anticlinal valleys adjacent to the cove cherts and shales of Middle and Upper Ordovician age are exposed. The igneous rocks are alkaline and, for the most part, belong to the nephelite syenite group. The peripheral intrusives, which are more resistant to erosion than those in the center of the basin, form an irregular ellipse. Contact metamorphism has altered shales and novaculites both outside and within the complex. There is also metamorphosed calcite of uncertain origin within the cove. The route of the excursion includes exposures of nephelite syenite and dike rocks, an alkalic pegmatite with a unique assemblage of minerals, metamorphosed calcite, magnetite, metamorphosed sandstone, jacupirangite, and rutile deposits.

## INTRODUCTION

Magnet Cove is an area of unusual petrologic and mineralogic interest lying in Hot Spring County about 12 miles east of Hot Springs, in southwest-central Arkansas. (See fig. 29.) It was known to the earliest travelers in this region as "The Cove," owing to its basinlike form. When the presence of bodies of magnetic iron ore became known, the name was changed to Magnet Cove. Long before the coming of the white man Magnet Cove was inhabited by Indians, whose flint arrowheads and stone implements are found in the soil at a number of localities.

Geologic study of the cove was begun by Featherstonhaugh in 1834, and from then until the present time the area has been visited by many geologists and mineralogists. In 1891 the posthumous report of J. Francis Williams on the igneous rocks of Arkansas (1)[1] was published. This volume contains three chapters on Magnet Cove which constitute a classic in petrographic and mineralogic literature. Further contributions to the petrogenesis were made by H. S. Washington in 1900 (2) and 1901 (3), and by K. K. Landes in 1931 (5).

[1] Numbers in parentheses refer to bibliography, p. 112.




DISTRIBUTION OF VARIETIES OF IGNEOUS ROCKS IN THE MAGNET COVE AREA, ARKANSAS

After H. S. Washington. The road shown is the route of the excursion, and the numbers indicate points referred to in the text.

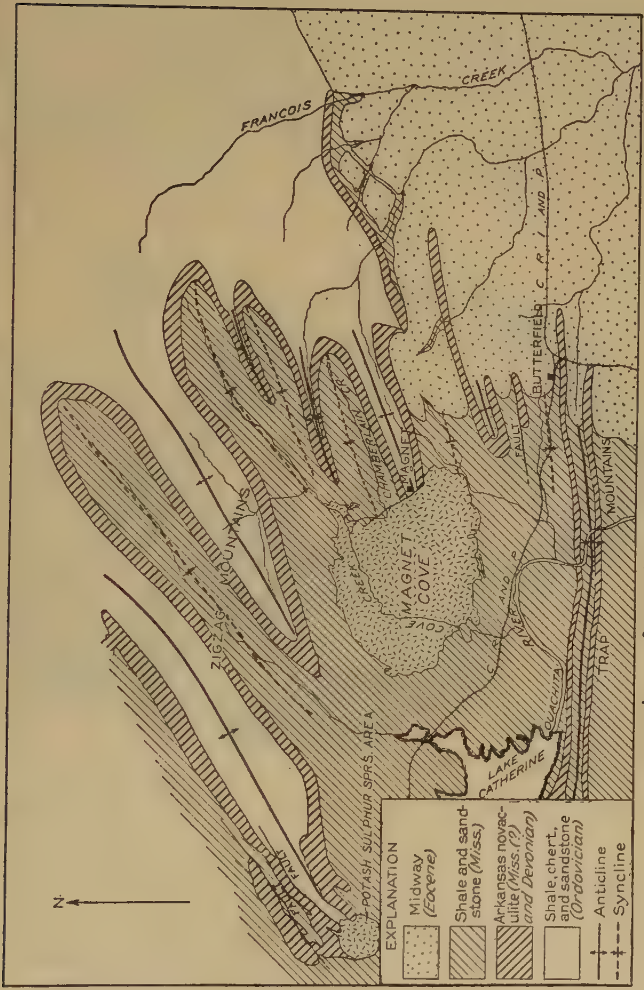



Figure 29.—Map showing location of Magnet Cove, Arkansas (After Bryan Parks)

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## GEOMORPHOLOGY

Magnet Cove lies near the southeastern border of the Ouachita geomorphic province, where the strongly folded Paleozoic rocks disappear beneath the Cenozoic sediments of the Gulf Coastal Plain (figs. 24 and 29). The ridges adjacent to the cove ares harp, narrow, and even-crested and are usually arranged in a zigzag pattern. The parallel or almost parallel ridges and valleys are the topographic expression of plunging anticlines and synclines.

The cove itself is an elliptical basin, with a northwest-southeast diameter of about 15,000 feet (4,572 meters) and a north-

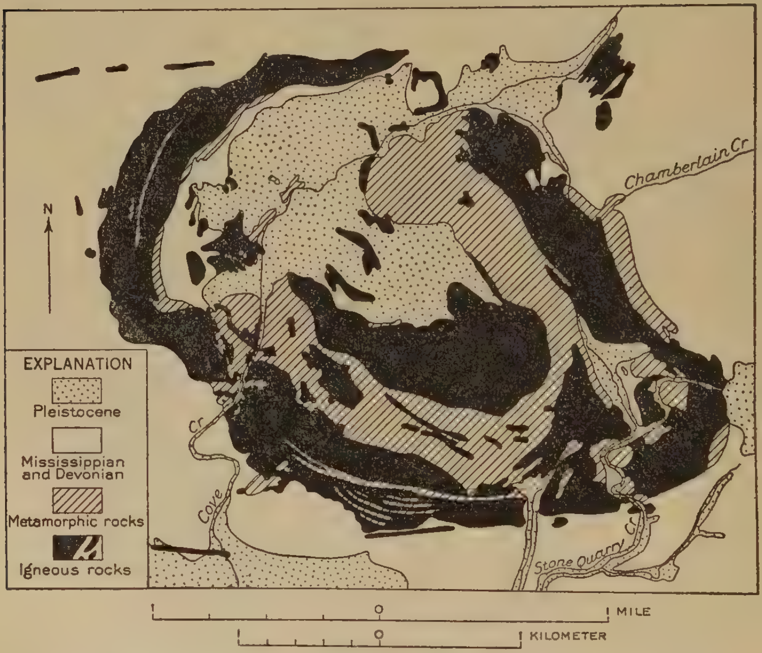


FIGURE 30.—Geologic map of Magnet Cove area. (After J. F. Williams)

east southwest diameter of about 10,000 feet (3,048 meters), and includes an area of about 5.1 square miles (13.2 square kilometers). The rim is broken through only at the northeastern and southwestern portions, where Cove Creek enters and leaves the cove. The floor of the inner part of the basin is relatively flat except for a 50-foot (15-meter) hill of tufa. The greatest relief of the cove ridges relative to the basin is about 190 feet (58 meters).

The sedimentary rock ridges outside of the cove are mostly covered with pine forests, whereas the cove itself is a region of deciduous hardwoods. The soil within the cove possesses relatively high fertility.

## REGIONAL GEOLOGY

The sedimentary rocks in the vicinity of Magnet Cove are of Paleozoic age. The Arkansas novaculite, a highly siliceous and resistant rock, forms the crest of the ridges. (See fig. 29.) The

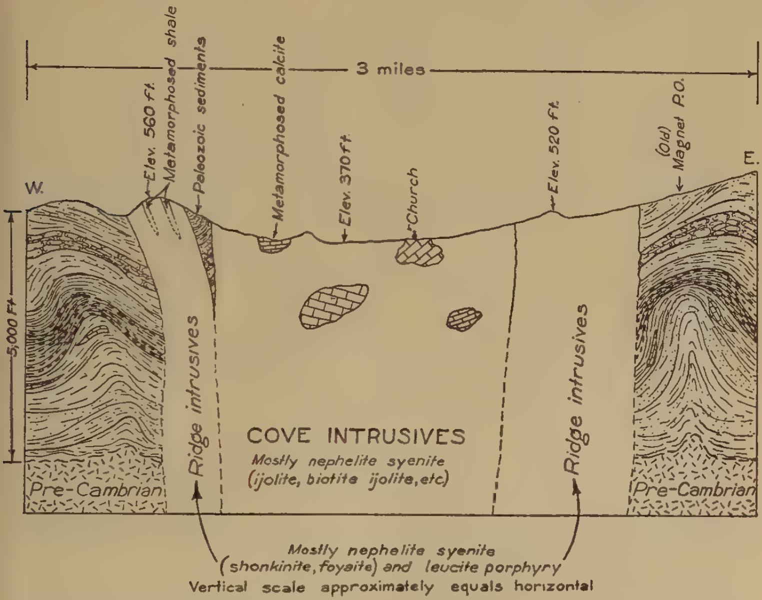


FIGURE 31.—Hypothetical cross section of Magnet Cove. (After Landes)

novaculite formation is of Devonian and possibly Mississippian age. The sandstones, shales, and novaculites adjacent to the cove have been contact metamorphosed. The shales in some places have been altered to "hornstones." The novaculite has been altered to a saccharoidal rock resembling soft sandstone. The zone of contact metamorphism does not extend more than a few hundred feet into the sedimentary beds. The sedimentary section cut by the Magnet Cove intrusives is shown in the following table:

| | Feet | Meters |
|---|---|---|
| Mississippian: | | |
| Stanley shale | 3,500+ | 1,067+ |
| Hot Springs sandstone | 0–200 | 0–61 |
| Mississippian (?) and Devonian: Arkansas novaculite | 100–800 | 30–244 |
| Silurian: | | |
| Missouri Mountain shale | 50–100 | 15–30 |
| Blaylock sandstone | 0–550 | 0–168 |
| Ordovician: | | |
| Big Fork chert | 700 | 213 |
| Womble shale | 250–900 | 76–274 |
| Blakely sandstone | 500 | 152 |
| Mazarn shale | | |
| Crystal Mountain sandstone | 850 | 259 |
| Cambrian: Collier shale | 200 | 61 |

## GEOLOGY OF MAGNET COVE

The areal geology of Magnet Cove is shown in Figure 30. A large part of the floor of the cove is covered by soil and alluvium. There are also two masses of calcareous or siliceous tufa, which are recent hot-spring deposits, and several bodies of coarsely crystalline contact-metamorphosed calcite. Igneous rocks crop out at a number of places, especially in the southern part, and undoubtedly underlie the alluvium, soil, and tufa in other parts of the basin.

The igneous rocks in the basin include a central mass or core, the Cove type of Williams, and a peripheral zone, the Ridge type of Williams. The rim of the cove comprises an inner belt of metamorphosed sediments and an outer belt of igneous rocks. Beyond the rim are a few small dikes.

Williams (1) believed that the rocks of the cove were formed during three distinct periods of igneous activity. The first provided the basic nephelitic rocks which constitute a large part of the interior basin. During the second period the intruded rocks cooled and cracked, and the cracks were filled with monchiquitic rocks. During the third period the nephelitic and leucitic rocks of the cove ring were formed and numerous tinguaitic dikes were intruded. Washington (2) believed that Magnet Cove probably represents a section of a laccolith and that the main rock types are differentiations in place. Landes (5) believes that the rocks of the interior Cove basin were formed during a first period of igneous activity as a stock and that the intrusives of the Ridge type were formed during a second period. (See fig. 31.)

The rock names on Plate 10 are those used by Washington in his paper of 1900. As they differ from the nomenclature of Williams and were changed somewhat in Washington's paper of 1901, the following correlation table is of service:

| Williams, 1890 | Washington, 1900 | Washington, 1901 |
|---|---|---|
| Eleolite-mica syenite, Cove type | Biotite ijolite.<br>Jacupirangite. | |
| Eleolite-garnet syenite, Ridge type | Ijolite. | |
| Eleolite syenite dike rock, Diamond Jo type | Foyaite. | |
| Eleolite syenite dike rock, fine grained | Shonkinite | Covite. |
| Eleolite tinguaite | Tinguaitic dikes. | |
| Leucite syenite dike rock<br>Leucite tinguaite | Leucite porphyry | Arkite. |
| Monchiquitic rocks | Monchiquitic dikes. | |

The distribution of the different varieties of igneous rocks is shown in Plate 10. These rocks are alkaline in character and are, in the main, varieties of nephelite syenite. Washington states that the rocks become decreasingly basic from the center to the rim of the complex. The magma was rich in titanium, as shown by the abundance of titanium minerals in the cove, both as primary minerals in the igneous rocks and as contact-metamorphic products. Quartz does not occur as a constituent of any of the igneous rocks. All the igneous rocks are intrusive.

Shale, sandstone, novaculite, and limestone were metamorphosed by the intrusion of the igneous rocks. The shales became dense, hard rocks which Williams called hornstones. Some of these are exposed among the ridge intrusives in elongated outcrops parallel to the border of the complex. The novaculites have been converted to crumbly saccharoidal sandstone with numerous vugs lined with quartz crystals. Many of the quartz euhedrons have perfect crystals of brookite perched upon them. The sandstones have been changed either to dense quartzitic rocks or to soft, friable rock impregnated with pyrite. There is also a coarsely crystalline calcite, containing a wide variety of contact-metamorphic minerals, the origin of which is uncertain. It has been suggested by Landes (5) that the calcite was originally part of a lower Paleozoic limestone that was carried up by the magma a distance of several thousand feet.

## ITINERARY

It is impossible in a limited time to make a detailed study of the various types of igneous rocks. Stops will be made at a number of localities where unusual mineral specimens and some of the most typical rocks may be collected. The route will cross the complex from west to east.

1.[2] Top of ridge. The contact between the sedimentary rocks and the igneous complex is at the bridge halfway up the western

[2] Numbers refer to Plate 10.

slope of the western rim of the cove. The rocks along the crest are foyaite and shonkinite. These nephelite syenites are gray, owing to the predominance of prismatic gray orthoclase crystals. Other megascopic minerals are smoky-colored nephelite, green-black aegirite, small scattered crystals of pyrite, and minute grains of purple fluorite. Small xenolithic inclusions oriented parallel to the trachytic texture are abundant. Throughout the cove the rocks have been extensively fractured and injected by small syenite dikes from ⅛ inch to 4 inches (0.3 to 10 centimeters) in width. Several of these dykes are seen here.

About 150 feet (46 meters) east of the crest is a good exposure of the metamorphic rocks.

The exposures in the road cut illustrate very well the nature of the rock weathering that is characteristic of the igneous rocks of the entire cove. Residual spheroidal masses are embedded in completely decomposed rock.

About 300 feet (61 meters) east of the crest and the same distance south of the road are two unusual facies of leucite porphyry. A phanerocrystalline leucocratic rock with phenocrysts of pseudoleucite more than 1 inch (2 centimeters) in diameter gives way within 100 feet (30 meters) to a dark-gray phanerocrystalline rock in which melanite garnet crystals as much as ¾ inch (1.9 centimeters) in diameter take the place of the pseudoleucite phenocrysts.

On the way to locality 2 outcrops of both metamorphosed shales and igneous rocks may be seen along the road.

2 (0.8 mile). Cove Creek bridge. Coarsely crystalline contact-metamorphosed calcite is exposed in the cut on the north side of the road. The calcite contains brown grains of monticellite and radiating sheafs of wollastonite. Magnetite and vesuvianite are also present. South of the road are many large fragments, which were blasted out of the road. Most of these are calcite, but a few are pegmatite and contain a unique assemblage of minerals. Large microline euhedrons, long black aegirite crystals, and irregular masses of greenish nephelite compose most of the pegmatite. Bright-pink grains of eudialyte occur with the aegirite. Astrophyllite and the secondary minerals epidote, manganopectolite, and eucolite may also be observed in this rock. The pegmatite was intruded into the calcite, and specimens may be found showing the contact, with distinct bands of metamorphic minerals in the calcite paralleling the pegmatite border.

Other localities near by may be visited. One of these is Perofskite Hill, a low mound south of the road. The soil here is residual and was probably derived from a second metamor-

phosed calcite mass. Loose crystals of perofskite and magnetite are abundant. Rutile eightlings are also found. Indian arrow heads, flints for scraping skins, stones for grinding, and other stone implements are found in the soil at this locality.

3 (1.2 miles). Ijolite and dike rocks. The rocks are exposed only as residual boulders as much as 18 inches (46 centimeters) in diameter. The first rock encountered along the path leading to the locality is ijolite. Most abundant is a mottled pink and black facies. Less abundant is an almost completely black facies. Both types are dense and hard and have a greasy to vitreous luster. They consist of nephelite (pink), melanite garnet (black), and accessory pyroxene.

Beyond the ijolite are boulders of metamorphosed rock. They are mostly light gray and show banding on weathered faces. The common type of metamorphosed rock elsewhere is very fine grained, is dark gray to black, and has a conchoidal fracture.

At locality 3 are boulders of monchiquite, tinguaite, and a few of shonkinite. The monchiquite is black and microcrystalline and contains amygdules and veinlets of calcite. It breaks with a hackly fracture. Although the tinguaite is called eleolite tinguaite by Williams, it is most easily recognized by its large lathlike feldspar phenocrysts, as much as ½ inch (1 centimeter) in size, which are embedded in a gray or black aphanitic groundmass. The color of the weathered rock is gray, and the feldspar phenocrysts weather out in relief to form intricate lacelike patterns.

4 (1.5 miles). Road cut and fill south of old church. The best collecting is in the blasted fragments along both sides of the road. Biotite ijolite, the rock in which the road was cut, is a coarse nephelite syenite of striking appearance. Besides salmon-colored masses of nephelite the rock contains schorlomite (garnet) in large and irregular shiny black anhedrons and scattered books of green and black biotite. The bed of the brook on the north side of the road is metamorphosed calcite containing abundant green mica.

Between localities 4 and 5 are two road cuts in weathered biotite ijolite. Many large sheets of altered biotite are seen in the banks. Books of mica 12 inches (30 centimeters) in diameter and 4 inches (10 centimeters) thick have been found.

5 (1.8 miles). Lodestone. Large fragments of magnetite are scattered over the surface in the cultivated fields on both sides of the road. About 5 per cent of them possess polarity. The magnetite has been residually concentrated through the weathering of a magnetite-rich igneous rock which underlies the soil at a depth of a few feet. Some specimens of magnetite are penetrated

by prisms of apatite and have white (altered) biotite attached to them. J. W. Kimzey, of Magnet, has observed that none of the magnetite in the bed rock is of the lodestone variety.

6 (2.9 miles). Old Magnet post office. Solutions given off by the igneous intrusives metamorphosed the sandstones and novaculite on the east side of the cove. Silica (probably derived from the siliceous rocks, as the magmas were low in silica) was deposited in cavities in the form of colorless, milky, and smoky quartz crystals. Relatively small crystals of brookite were then deposited on the prism and pyramid faces of the quartz. Specimens of these minerals are obtained in the roadside ditches and in the fields adjacent to old Magnet post office. The best collecting is on the top of the low hill 600 feet (183 meters) southeast of the stop.

7 (4.2 miles). Cove Creek runs over jacupirangite for more than 1,000 feet (305 meters). It is a very heavy black coarse-grained rock composed of brown and green augite, magnetite, accessory biotite, and interstitial nephelite. It has been greatly shattered, and the fractures are penetrated by light-colored syenite dikes from ⅛ inch to 6 inches (0.3 to 15 centimeters) wide. Good exposures 20 to 30 feet (6 to 9 meters) high occur along the stream.

8 (5.4 miles). Rutile locality. The soil at the north end of the plowed field contains pseudomorphs of limonite after pyrite. The south end of the field, along with the uncultivated tract immediately west, contains loose crystals of rutile. Some of these are pseudomorphic after brookite. In a few places the plow has broken out fragments of the rutile-bearing bed rock and clusters of rutile crystals weighing as much as 40 pounds (18 kilograms). The titanium dioxide content of both the soil and the bedrock is sufficiently high in this locality to render exploitation a commercial possibility.

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# THE BIRMINGHAM DISTRICT, ALABAMA

By Ernest F. Burchard

ABSTRACT

The Birmingham district, Alabama, lies partly in the Valley and Ridge province and partly in the Appalachian Plateaus. Birmingham Valley extends along an anticlinal axis in highly folded rocks between portions of the plateau formed on nearly horizontal rocks.

The rocks are all sediments, comprising a thickness of more than 20,000 feet (6,096 meters), the oldest of Cambrian age. The Cambrian, Ordovician, and Mississippian rocks contain dolomite and limestone of value for flux; the Silurian and Cretaceous rocks contain iron ore; and the Pottsville (Pennsylvanian) beds contain coking coal. Birmingham is one of the few places in the world where the three basic raw materials, iron ore, coking coal, and flux are found in great abundance within a few miles of each other, and a large iron and steel industry has developed in consequence.

Hematite of the Silurian Red Mountain formation constitutes 90 per cent of the ore supply. It occurs in a bed of remarkable uniformity of thickness and composition, outcropping for a distance of about 20 miles (32 kilometers) and dipping southeastward. The workable ore ranges from 7 to 12 feet (2 to 3.6 meters) in thickness and averages about 36 per cent of iron. Limonite, or brown iron ore, which supplies 9 to 10 per cent of the ore used, is found in the valley at the contact of the Cambrian limestone and Cretaceous clay and sand. Coking coal occurs in the Warrior field in quantities sufficient to smelt all the available iron ore, and the Cahaba and Coosa Basins contain coal suitable for domestic, steam, and gas purposes. The abundance of these natural resources insures long continued industrial activity at Birmingham.

## GEOGRAPHY

The Birmingham district is situated in the north-central part of Alabama and comprises an area measuring 75 miles (121 kilometers) from northeast to southwest and 40 miles (64 kilometers) from northwest to southeast. The district lies partly in the Valley and Ridge province of the Appalachian Highlands and partly in the Appalachian Plateaus. (See pl. 11.) The portion known as Birmingham Valley extends along an anticlinal axis between portions of the plateau which are formed on more nearly horizontal rocks. The topography of the district, which has been controlled by the structure and character of the underlying rocks, has an important bearing on its settlement and industrial development. The valley is characterized by long, narrow, canoe-shaped troughs, in general parallel to one another, trending N. 30°–40° E. and separated by well-defined ridges. The troughs are developed mainly on the most soluble rocks, along the axes of anticlines; the most enduring strata on

the limbs of the folds form the rims of the valleys. At intervals of 2 to 5 miles (3.2 to 8 kilometers) are natural openings or "gaps" in the ridges, which afford convenient passageways between the valleys. With respect to its bounding ridges the Birmingham Valley is really a valley, but in respect to the main drainageways of the region, the Black Warrior and Cahaba Rivers, it marks a divide from which the water is drained mainly into the Black Warrior. There are no large streams in the valley, but an adequate supply of water for the city of Birmingham is obtained by pumping from the Cahaba River. A large artificial lake for the storage of water from tributaries of the Black Warrior River furnishes supplies for certain industrial purposes.

The abundance and fortunate grouping of the raw materials for iron and steel making, a climate in which out of door work can be carried on throughout the year, a practically unlimited area suitable for manufacturing sites, topography favoring access by railroads, and low-cost water transportation by way of the Black Warrior River to the Gulf of Mexico are among the natural advantages enjoyed by the Birmingham district.

The Birmingham district is the greatest iron center in the South, is second in rank in iron-ore production in the United States, and may prove to be the longest-lived iron-ore mining district in the country. Its industrial history dates back only to the late sixties, or since the Civil War. Noteworthy steps in the development of this district were the successful manufacture of pig iron with coke for fuel at the old Oxmoor furnace in 1876, the opening of the Pratt mines of coking coal in 1879, the making of open-hearth steel in 1899, and the present-day manufacture of a great variety of iron and steel products. The population of the city is 260,000 and of the district 383,000.

## PRODUCTION OF RAW MATERIALS

The annual production of hematite in the Birmingham district from 1907 to 1930 has ranged between 2,500,000 and 6,315,000 gross tons (2,540,000 and 6,416,000 metric tons). (See fig. 32.) The whole production in this period has been 109,000,000 gross tons (110,749,000 metric tons) and the total production since the beginning of mining is estimated at about 146,000,000 gross tons (148,343,000 metric tons). From 1907 to 1930 the annual production of brown ore has ranged between 180,000 and 525,000 gross tons (183,000 and 533,000 metric tons); the whole production during that period has been about 9,500,000 tons (9,652,000 metric tons), and the total output since mining began approximates 15,000,000 gross tons (15,241,000 metric tons). The output of pig iron in the district from 1911 to 1930

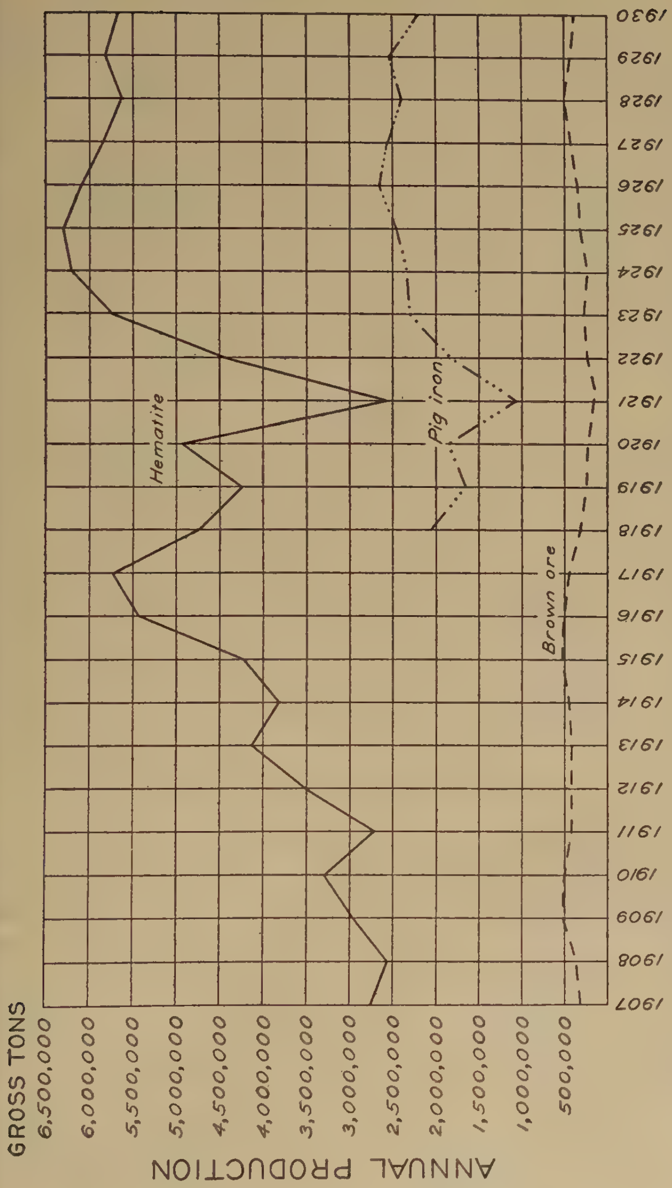



FIGURE 32.—Production of hematite, brown ore, and pig iron in the Birmingham district, Alabama, 1907–1930

has ranged between 1,062,000 and 2,600,000 gross tons (1,079,-000 and 2,642,000 metric tons) annually (see fig. 32), and the total output during this period has been more than 40,000,000 gross tons (40,642,000 metric tons). Much of the Birmingham pig iron is used directly as hot metal in the manufacture of open-hearth steel.

The coal and coke produced in Alabama come mostly from the Birmingham district. The annual coal production has ranged in 24 years between 11,523,000 and 21,001,000 net tons (10,453,000 and 19,052,000 metric tons), and that of coke between 2,335,000 and 4,868,000 net tons (2,118,000 and 4,416,000 metric tons). The total output of coal has been approximately 557,471,000 net tons (495,729,000 metric tons) and that of coke 125,000,000 net tons (113,398,000 metric tons).

## GEOLOGY

The rocks exposed in the Birmingham district are all of sedimentary origin and have a thickness of more than 20,000 feet (6,096 meters). Those of commercial importance are dolomite and limestone of Cambrian, Ordovician, and Carboniferous age, of value for flux and the manufacture of lime and cement; the Silurian rocks, or Red Mountain formation (of Clinton and Medina age), containing the beds of red iron ore; the Pennsylvanian (Pottsville formation), the carrier of the beds of coal; and the Upper Cretaceous (Tuscaloosa formation) and Pliocene (Citronelle formation) clays and sands, in which the deposits of brown iron ore are found. A generalized section of the rocks of the district is as follows:

*Generalized section of rocks in Birmingham district*

| | Feet | Meters |
|---|---|---|
| Tertiary and Cretaceous: Clay, sand, and gravel in extreme southwestern portion of district | 5–250 | 1.5–76 |
| Pennsylvanian: Pottsville formation ("Coal Measures"), sandstone and shale | 2,600–9,000 | 792–2,743 |
| Mississippian: Shale, sandstone, limestone, and chert | 1,800–3,300 | 549–1,006 |
| Devonian: Shale and sandstone | 1–40 | 0.3–12 |
| Silurian: Red Mountain formation, sandstone, shale, and iron ore | 235–400 | 72–122 |
| Ordovician: Limestone | 1,750–2,000 | 533–610 |
| Upper Cambrian: Dolomite | 5,500 | 1,676 |
| Cambrian: Limestone, shale, and quartzite | 4,000–4,800 | 1,219–1,463 |

The geologic structure of Birmingham Valley is in general anticlinal, and the fold is crumpled and faulted along its median line and has unsymmetrical limbs. (See fig. 33.) The rocks in Red Mountain, on the southeast, which contain the workable

beds of red iron ore, dip 15°–45° SE., but in West Red Mountain, on the northwest, they dip very steeply or are vertical and even overturned and are in places cut out by faults. In Shades Valley and in the bordering coal fields, especially the Warrior field, the rocks are flatter but more or less faulted. The geologic structure of Shades Valley has an important bearing on the depth and attitude of the beds of red iron ore that underlie it.

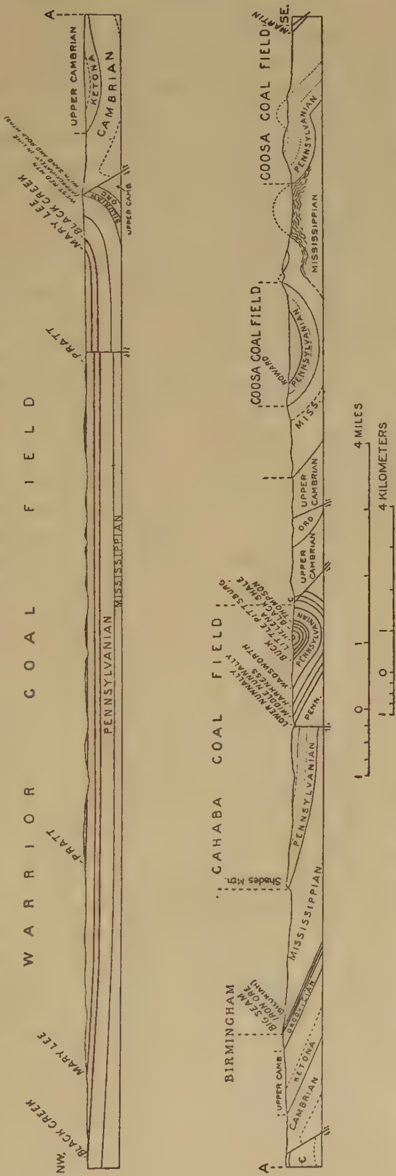



FIGURE 33.—Geologic structure section across Birmingham Valley. Є, Cambrian; Ord., Ordovician; Miss., Mississippian; Penn., Pennsylvanian

## IRON ORE

More than 90 per cent of the iron ore produced in the district has been red hematite, and between 9 and 10 per cent brown ore.

### HEMATITE OF RED MOUNTAIN FORMATION

The Red Mountain formation consists of sandstone, shale, and iron ore. The thickness ranges from 235 feet (72 meters) near Bessemer to 360 feet (110 meters) or more in the northeastern part of the district. The unweathered iron ore and some of the sandstone beds are calcareous. There is generally a sharp demarcation between beds of iron ore, shale, and sandstone.

The ore-bearing formation crops out along the crest of Red Mountain and extends below Shades Valley and the Cahaba coal field

probably to the Helena fault, which marks the southeas border of that coal field, a distance of 6 to 8 miles (9.6 t 12.8 kilometers) across the strike. On West Red Mountain th formation crops out in disconnected narrow strips broken b faults, and deep drill holes have proved a westward extension fo many miles beneath the Warrior coal field. The rocks in Re Mountain and West Red Mountain, which are only 6 or 7 mile (9.6 to 11.2 kilometers) apart, can not be correlated closely, an it may be that they were deposited in separate basins and neve formed continuous strata across the anticlinal arch of Birming ham Valley. Only in Red Mountain is the ore of value.

Four iron-bearing beds occur, but only one of them, the "Bi seam," is of present commercial importance.

*Irondale seam.*—The Irondale is stratigraphically the lowes of the iron-bearing beds. Its thickness ranges from 2 to 8 fee (0.6 to 2.4 meters). Its soft ore, long ago practically all mine out by surface trenches or shallow drifts, was of the best qualit in the district. Little of its hard ore has been mined because o the high cost of recovery. The Irondale and Big seams ar sharply separated by sandstone, shale, or conglomerate and diffe so much in quality that they have been mined separately.

*Big seam.*—The workable portion of the Big seam of red or extends more than 20 miles (32 kilometers) along Red Moun tain. The thickness ranges from 16 to 30 feet (4.8 to 9.1 meters) but there is rarely more than 10 to 12 feet (3 to 3.6 meters) o good ore in a single section, locally termed a "bench," and a most places only 7 to 10 feet (2.1 to 3 meters) is mined. Fror northeast to southwest the total thickness of the iron-bearin sediments gradually decreases, without, however, altering greatl the thickness of the workable portion. About the middle o the outcrop area the bed becomes separated into two benche either by a well-defined parting along the bedding plane or b a shale bed, which thickens gradually to the southwest. Th upper bench of the Big seam is generally the workable part, bu the lower bench contains in its upper part between Birminghar and Bessemer a few feet of ore a little more siliceous than th upper bench. At the southwest end of the district both benche become shaly and contain only ore of very low grade.

*Hickory Nut and Ida seams.*—Two ferruginous beds, 6 inche to 2 feet (0.15 to 0.6 meter) thick, 15 to 60 feet (4.5 to 1 meters) above the Big seam, have locally been termed "ore seams, but they do not contain valuable ore. The upper, o Ida seam, of coarse siliceous material, is the most persisten having been traced from Irondale to Bessemer, a distance o 17 miles (27 kilometers). The Hickory Nut seam, a ferruginou limestone, derives its name from the presence of many casts o

the brachiopod *Pentamerus oblongus*, which resembles the partly open hull of a hickory nut.

*Character of the ore.*—The Red Mountain ore consists essentially of amorphous, nonhydrous red hematite, intimately mixed with varying percentages of calcium carbonate, silica, alumina, magnesium carbonate, and other minerals in minor proportions. In places the ore is oolitic, and some beds are very fossiliferous. Locally the ore beds are largely composed of fine to coarse grains of silica, coated and cemented with ferric oxide. According as the ore is high or low in lime carbonate it is termed "hard" or "soft" ore. The soft ore has resulted from the leaching by downward-percolating waters of the soluble lime carbonate contained in the original hard ore. This alteration extends down the dip to varying distances that depend on the thickness and permeability of the cover. With the removal of the lime carbonate the relative percentages of the remaining less soluble constituents, mainly iron oxide, silica, and alumina, are increased. Very little soft ore now remains in the Birmingham district except where the silica is high. The following analyses show a typical hard ore (No. 1) and a typical soft ore (No. 4), with intermediate or semihard grades (Nos. 2 and 3) all from the same mine slope.

*Analyses of bedded hematite, showing gradation from hard to soft ore*

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Iron, metallic (Fe) | 37.00 | 45.70 | 50.44 | 54.70 |
| Silica ($SiO_2$) | 7.14 | 12.76 | 12.10 | 13.70 |
| Alumina ($Al_2O_3$) | 3.81 | 4.74 | 6.06 | 5.66 |
| Lime (CaO) | 19.20 | 8.70 | 4.65 | .50 |
| Manganese (Mn) | .23 | .19 | .21 | .23 |
| Sulphur (S) | .08 | .08 | .07 | .08 |
| Phosphorus (P) | .30 | .49 | .46 | .10 |

Although the soft ore carries more iron, some of the hard ore has the advantage of containing enough lime to flux the silica that it contains. To hard ores that contain more lime than is needed for fluxing, soft red ore or brown ore may be added to take up the excess lime. The iron content of the red ore shipped in 1930 ranged from 33.03 to 38.50 per cent and averaged 36.61 per cent.

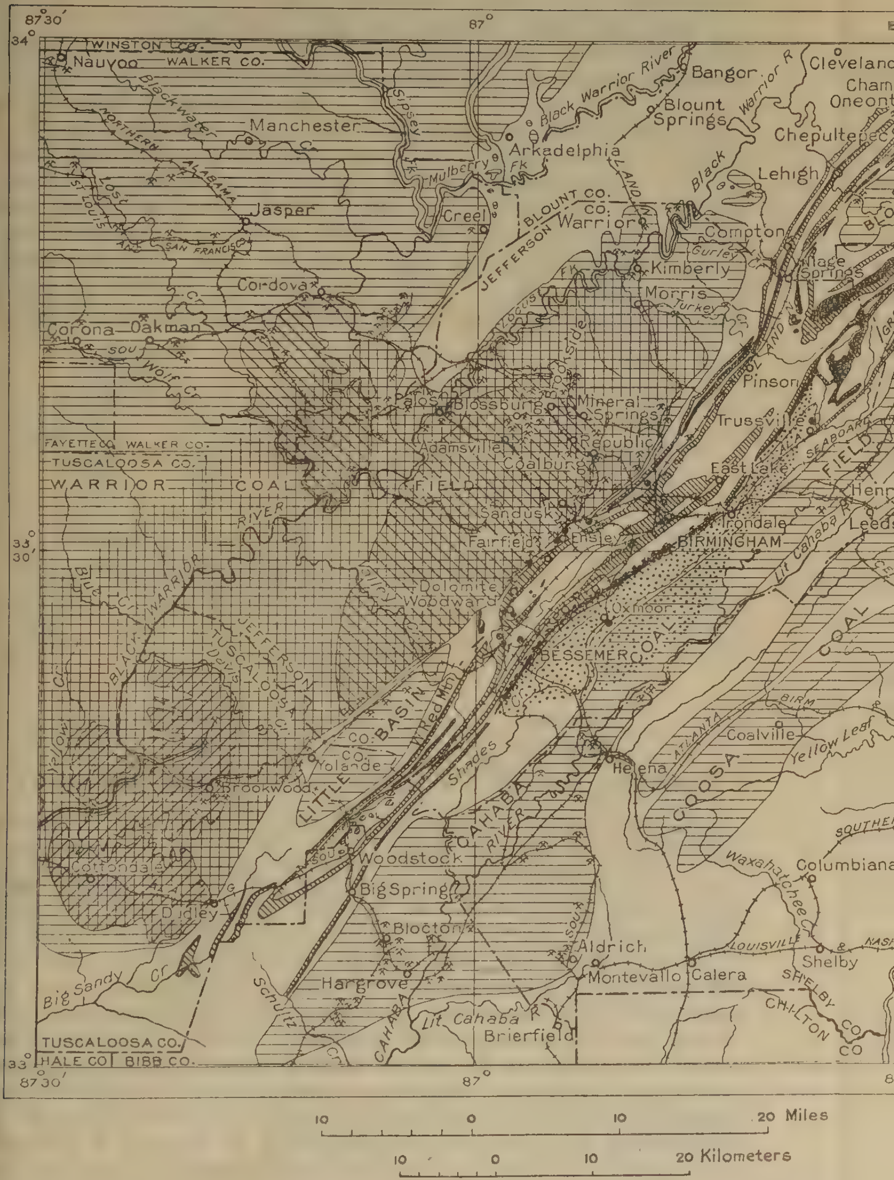
*Mining.*—The mining of Red Mountain ore was at first confined to the outcrop, the overlying measures being stripped in some places to a depth of 30 feet (9 meters). The second stage of mining consisted in sinking slopes in or below the ore, approximately at a right angle to the strike. The ore is dumped directly

from 5-ton steel cars at the workings into 12-ton steel skips. At intervals of 60 feet (18 meters) working headings are turned off in pairs, driven "narrow" 75 feet (22.8 meters) from the slope, and manways are raised for ventilation. The headings are then widened and driven at a width of 30 feet (9 meters) to the property boundary. At intervals of 200 feet (61 meters) raises or upsets are driven between headings to maintain natural ventilation. By this method 70 per cent of the ore is mined, 30 per cent being left as pillars to support the overlying measures and protect the mines from inflows of water. The protective pillars will be mined when development work has ceased, and the ore will be recovered on the retreating system. The skips are hoisted by first-motion hoisting engines and motors, which automatically dump into ore pockets at the surface, from which the ore is fed by gravity into gyratory crushers discharging direct into railroad cars.

At present practically all mining openings on Red Mountain are slopes from the outcrop ranging in length from 4,000 to 6,000 feet (1,219 to 1,829 meters), the thickness of strata over the advanced workings ranges from 1,000 to 1,500 feet (305 to 457 meters). At the Shannon mine, near Oxmoor, in Shades Valley, the ore, 2,000 to 3,000 feet (610 to 914 meters) below the surface, is reached by a 51° inclined shaft.

*Practical significance of origin.*—The question as to how the red ore was formed has a practical bearing on the extent and quality of unexploited ore. The soft ore merges more or less gradually into hard ore with depth. The mode of occurrence and the constitution of the hard ore do not indicate that it has resulted from the alteration of a rock originally very different in composition, or that it is directly residual from disintegration of rocks containing minor quantities of iron minerals. The hard ore must therefore be regarded as having been formed by sedimentation in essentially its present condition. Where lime was replaced by iron this process probably occurred while the sediments were being laid down, or before the beds were brought into their present position. Consequently, no regular decrease in iron content is to be expected as the ore beds are explored to greater depths. It has been found that the iron content has remained fairly constant or even increased slightly in certain places with distance from the outcrop. Additional evidence of original deposition is found in an alternation of layers within the ore bed which contain higher and lower percentages of silica, with the variations in lime in the reverse order.

The ore beds, in common with the inclosing strata, are built up of overlapping thin layers of sedimentary material; therefore, they probably are comparable in length and width with indi-




MAP OF THE BIRMINGHAM DISTRICT, ALABAMA

vidual lenses of sandstone and shale in the formation. The beds are of course very thin in proportion to their other dimensions. In some directions they wedge out, and in others they split into thin seams and dovetail with beds of shale and sandstone. The sedimentary character makes possible fairly accurate estimates of probable tonnage of ore.

*Geologic structure of ore field.*—The ore beds in Red Mountain for a distance of about 2,300 feet (701 meters) from the outcrop and to a vertical depth of about 750 feet (229 meters), or a few feet below sea level, dip at angles ranging from 15° to 45° but averaging less than 30°. The strata flatten where they pass from Red Mountain under Shades Valley, and in places they rise in a low arch farther east below the valley. In the southwestern 12 miles (19 kilometers) of the ore field there is a zone of faults

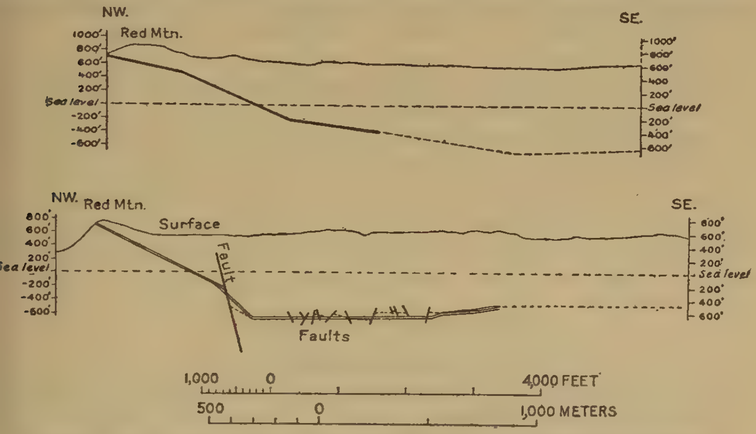



FIGURE 34.—Typical profiles of red-ore mines in the Birmingham district

along the southeast foot of Red Mountain. These faults trend, in general, parallel to the ridge. Their throw in the mine workings ranges from 15 to 500 feet (4.5 to 152 meters), and their dips are nearly vertical. Two or more faults are encountered in some mine slopes, but in others there are none. (See fig. 34.) Drilling and extended slope driving have shown that the zone of strike faults is not confined to a narrow strip beneath the southeast foot of Red Mountain, but that faults may be expected to intersect the ore bed at several places beneath Shades Valley and beneath the escarpment of Shades Mountain, which is the farthest east at which mining operations on red ore are active.

*Reserves of red ore.*—The writer estimates for the Birmingham district a reserve of 1,431,500,000 gross tons (1,454,474,000 metric tons) of first-grade red ore above a depth of 3,500 to 4,000

feet (1,067 to 1,219 meters). In addition, approximately 500,000,000 gross tons (508,000,000 metric tons) of second-grade ore, mainly in the lower part of the Big seam, is possibly available. This gives a grand total of first and second grade red ores of approximately 1,931,500,000 gross tons (1,962,474,000 metric tons), but the total future recovery may fall short of this figure because of structural conditions, premature caving of roof, and greater depth, which may reduce the percentage of recovery.

### BROWN IRON ORE

Brown iron ore, a mixture of hydrous oxides of iron, was formerly the sole source of the iron made in many of the small charcoal furnaces. Most of the brown ore supplied to the Birmingham furnaces has come from Woodstock and Champion, southwest and northeast of Birmingham. The ore occurs in irregular masses in Cretaceous and Tertiary clay, sand, and gravel, at or near the contact with Cambrian limestone and dolomite. The larger deposits of ore occur in old stream and solution channels and hollows in the limestone, and some are related to faults. In places the deposits reach a thickness of 75 to 125 feet (23 to 38 meters).

The brown ore requires concentration by log washers and jigs to remove clay, sand, and gravel. A representative sample of washed, picked, and screened brown ore shows on analysis Fe, 50.39 per cent; $SiO_2$, 13.02; $Al_2O_3$, 2.41; Mn, 0.82; P, 0.32; moisture, 5.38.

### FLUXING MATERIAL

Both dolomite and limestone are used for furnace flux in the Birmingham district. The formations that contain stone suitable for flux are the Ketona dolomite, of Upper Cambrian age; the Chickamauga limestone, of Ordovician age; and the Warsaw limestone, of Mississippian age. The Ketona dolomite occurs in abundance and supplies all the blast-furnace flux used in the district. It is a true dolomite with a silica content of 0.5 to 1.3 per cent. The limestone is used in open-hearth steel furnaces. A typical sample carries 1.62 per cent of $SiO_2$ and 1.22 per cent of $MgCO_3$. The dolomite and limestone beds are exposed extensively along Birmingham Valley. (See pl. 11.)

## COAL

### POTTSVILLE FORMATION ("COAL MEASURES")

Unconformably overlying the Mississippian rocks are the Pennsylvanian (Pottsville) coal-bearing rocks. These rocks occupy broad troughs, synclines, or basins in which they have been preserved from erosion. The important coal-bearing areas

are the Warrior field, the Coosa Basin, and the Cahaba Basin, named from the respective rivers that drain them. (See pl. 11.)

A stratum of sandstone 100 to 600 feet (30 to 183 meters) thick (the "Millstone grit" of the Alabama Geological Survey) occurs at the base of the Pottsville formation. The remaining Pottsville rocks are shale and sandstone with coal beds. In the Warrior field these rocks are 2,600 to 3,000 feet (792 to 914 meters) thick; in the Cahaba and Coosa fields they are much thicker.

*Warrior field.*—There are five important coal beds in the Warrior field, the highest of which is about 2,500 feet (762 meters) stratigraphically above the lowest. Throughout most of the Warrior field the rocks lie nearly flat. Along a narrow zone at the southeast margin, however, they dip along the outcrop 15°–80° NW. From Birmingham southwestward the field is affected by normal faults trending nearly due north, which form a serious obstacle to mining. The roof and floor of the coal beds of this field are almost everywhere strong.

*Cahaba Basin.*—The Cahaba Basin is a narrow syncline 68 miles (109 kilometers) long and about 6 miles (9.6 kilometers) wide. There are many workable seams, and the total quantity of coal is large. Coal from the Cahaba field is excellent for domestic, steam, and gas purposes. A representative analysis shows moisture, 2.25 per cent; volatile matter, 36.79; fixed carbon, 55.37; ash, 5.59; sulphur, 0.63.

*Coosa Basin.*—The Coosa Basin is a deep syncline 60 miles (97 kilometers) long by 6 miles (9.6 kilometers) wide, forming the southeast margin of the Alabama coal fields. It has not been thoroughly explored. The best known part is the northern end in the vicinity of Coal City and Ragland, where 2 to 12 seams are reported having a thickness of 3 feet (0.9 meter) or more.

*Area and tonnage of fields.*—The area and estimated coal tonnage of the principal Alabama coal fields are summarized in the table below.

*Area and estimated original tonnage of the principal Alabama coal fields*

| | Area | | Estimated coal | |
|---|---|---|---|---|
| | Square miles | Square kilometers | Net tons | Metric tons |
| Warrior field | 3,500 | 9,065 | 59,826,968,000 | 54,274,072,000 |
| Coosa Basin | 260 | 673 | 2,396,160,000 | 2,173,760,000 |
| Cahaba Basin | 325 | 842 | 2,994,200,000 | 2,716,293,000 |
| | 4,085 | 10,580 | 65,217,328,000 | 59,164,125,000 |

## COKING-COAL BEDS

The fuel used in the blast furnaces of Alabama is coke, made from coal mined in the Warrior field, almost entirely in by-product ovens. Coal from certain beds of the Cahaba field also yields good coke, but owing to the generally higher amount of volatile matter in the Cahaba coals they yield less coke than those of the Warrior field, and their coking has been discontinued.

The physical make-up of the several coal beds differs greatly. Some are comparatively free from impurities in the form of clay partings; others are very dirty. Considerable sulphur in the form of iron pyrite is disseminated through the coal and in some of the thin partings. These impurities must be washed from the dirtier coals before they will make coke fit for blast-furnace use, and from the cleaner beds before the coal will make the best grade of coke.

Typical analyses of these coals are given below:

*Analyses of coking coals from Warrior field*

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Volatile matter | 26.07 | 28.52 | 30.10 | 30.80 | 31.92 |
| Fixed carbon | 57.33 | 63.75 | 61.63 | 63.91 | 57.29 |
| Ash | 16.60 | 8.00 | 8.27 | 5.29 | 8.00 |
| Sulphur | .86 | .74 | 1.53 | 1.28 | 1.27 |

1. Representative unwashed coal from Mary Lee group (dry basis).
2. Representative washed coal from Mary Lee group (dry basis).
3. Representative unwashed coal from Pratt bed (dry basis).
4. Representative washed coal from Pratt bed (dry basis).
5. Average of 5 samples from Brookwood group.

It is estimated that nearly 4,000,000,000 tons (3,628,740,000 metric tons) remains unmined in the three best beds of coking coal alone, of which about 75 per cent may be recoverable.

The Pratt seam is mined by slopes from the outcrop and by shafts in the flat-lying coal west of the outcrop in the Warrior field. The room and pillar method of mining is generally used. There are many installations of electric haulage and electric undercutting machines. In the Coosa field, which is small and not yet a large producer, many of the coal seams crop out and are mined from drifts or slopes.

## DURATION OF RAW MATERIALS

The Birmingham district may be the longest-lived iron-mining district in the United States. The ore has to be mined by underground methods and hauled out little by little through long slopes, so that production can never be as rapid as in the open-pit mines of the Mesabi range, in the Lake Superior district. The known ore reserves in the two districts are each about 2,000,000,000 tons (2,032,090,000 metric tons), but the yearly output in the Birmingham district is 5,000,000 to 6,000,000 tons (5,080,000 to 6,096,000 metric tons), whereas the Lake Superior output is ten times as great. In emergencies the output from the Mesabi open-pit mines is capable of rapid and large increases, but that of the Birmingham mines is strictly limited by physical conditions. At the present rate of production the iron-ore reserves of the Birmingham district should last more than 300 years, but those of present commercial grade in the Lake Superior district appear to be limited to about 30 years. These figures may, however, be altered by changes in the rates of production and consumption, the discovery of new ore bodies, improved methods of saving, cleaning, and utilizing low-grade ores, and the use of scrap metal.

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# THE ORE DEPOSITS OF THE CARTERSVILLE DISTRICT, GEORGIA

By Geoffrey W. Crickmay

ABSTRACT

The Cartersville district, in northwestern Georgia, contains deposits of manganese, iron, barite, and ocher. At present manganese and barite stand foremost in value of output. The deposits occur along the eastern margin of the Appalachian Valley in early Cambrian and pre-Cambrian rocks. Iron (in the form of limonite) and ocher are mined only from bedrock; manganese (manganite, pyrolusite, and psilomelane) and barite are obtained only from unconsolidated clay and gravel of residual, colluvial, and alluvial origin. In general, manganese and iron occur in the northern part of the district; barite and ocher in the southern part.

## INTRODUCTION

The Cartersville district presents variations of a type of ore deposit common throughout the southern Appalachian Mountains. It was one of the first producing areas of manganese in the United States (Dobbins mine, 1866). Though the deposits have been examined by many geologists and described in considerable detail, there is not yet complete agreement as to their origin.

*Location.*—The Cartersville district lies in northwestern Georgia, in the eastern portion of Bartow County. Cartersville, a city of 5,250 population, is the center of mining developments in the region and a junction point of the Louisville & Nashville and Nashville, Chattanooga & St. Louis Railways, which together afford direct shipping routes to the north and south.

*Drainage.*—The southern part of the district is drained by the Etowah River and its tributaries. The northern part is drained by branches of Pinelog Creek, which flows into the Coosawattee River. In most places there is an abundance of water for mining operations.

*Topography.*—The region presents a series of ridges and irregular spurs arranged linearly in a north-south direction. The main ridge, on which the highest altitudes are found, extends from Bartow in a northerly direction through Signal Mountain (1,300 feet, or 396 meters) and Pine Mountain (1,625 feet, or 495 meters) to Pinelog Mountain, whose main summit has an altitude of 2,400 feet (732 meters). The Etowah River, the only stream which breaks through this ridge, has an altitude of 694 feet (212 meters) near Cartersville. There is a maximum

relief of over 1,500 feet (457 meters), but generally the relief is less than half of that figure. The ore deposits are found mainly on the hills lying immediately to the west of the Signal-Pinelog ridge, but a few occur on the east side.

*Climate.*—The climate of northwestern Georgia is characterized by moderate rainfall (mean annual precipitation 49.6 inches, or 1.25 meters) and high average temperature (61.2° F.). The summer and winter months have the greatest rainfall; the spring and autumn months are relatively dry. The average monthly temperature ranges from 79.5° F. in July to 42.2° F. in January. These climatic conditions are controlling factors both of the depth of weathering, which is uncommonly deep in the area, and of the secondary concentration of the ores by the action of meteoric waters.

*Population and industries.*—The rough ridge country east of Cartersville is almost uninhabited; the more level country to the west and to the east of the ridge supports a meager population. The greater part of the inhabitants are engaged in agriculture; cotton and corn are the principal crops. The mining industry has in the past held an important position, but now only a few mines maintain steady production.

## GEOMORPHIC DIVISIONS

The southern Appalachians in Georgia are divisible into four geomorphic provinces—from west to east the Appalachian Plateaus, the Valley and Ridge province, the Blue Ridge province, and the Piedmont province. The mountains of the Blue Ridge province are restricted to the northern part of Georgia, so that the Valley and Ridge province in its southern part is bordered on the southeast directly by the Piedmont province. The boundary between these two provinces runs in a northerly direction through the Cartersville district.

## GENERAL GEOLOGY

The geology of the Valley and Ridge province differs markedly from that of the Piedmont province. The Valley and Ridge province is occupied by slightly metamorphosed Paleozoic sediments; the Piedmont Plateau is made up of sedimentary and igneous rocks, all greatly metamorphosed and now represented, for the most part, by crystalline schists and gneisses. The age of these schists and gneisses is uncertain. Recent investigations indicate that the metamorphic rocks are older than any of the Paleozoic formations in the valley and therefore are probably pre-Cambrian.

The geology of the Cartersville region is shown on Plate 12.

## STRATIGRAPHY

The stratigraphy in the Cartersville district may be summarized as follows:

*Formations in the Cartersville district*

VALLEY AND RIDGE PROVINCE

| | Feet | Meters |
|---|---|---|
| Upper Cambrian: | | |
| Knox dolomite: Thick-bedded gray magnesian limestone and dolomite | 2,000 | 610 |
| Conasauga formation: Olive-green clay shale and thin-bedded limestone | 1,000–4,000 | 305–1,219 |
| Lower or Middle Cambrian: Cartersville formation: Shale, sericitic schists, and sandstone | 600–1,000 | 183–305 |
| Lower Cambrian: | | |
| Shady limestone: Gray massive limestone | 800–1,500 | 244–457 |
| Weisner quartzite: White and gray quartzite and gray sericitic schist | 2,000–5,000 | 610–1,524 |

PIEDMONT PROVINCE

Probably pre-Cambrian (sequence and thickness not known):
- Mica schist, graphitic phyllite, quartzite, and fine-grained quartz conglomerate.

Igneous:
- Hornblende schist.
- Augen gneiss.
- Quartz-biotite gneiss.

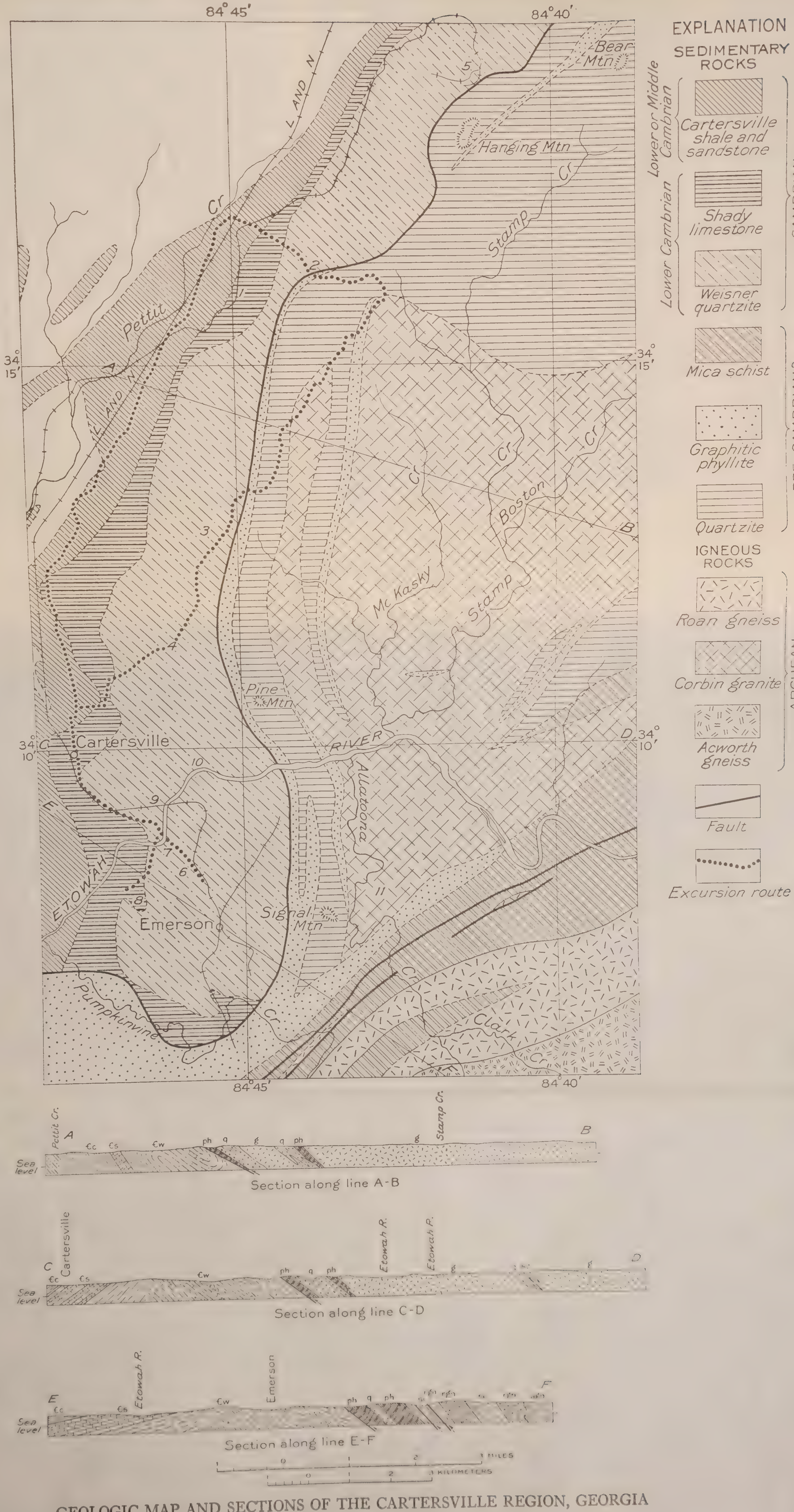
Of these formations the pre-Cambrian (?) quartzite, the Weisner quartzite, the Shady limestone, and to a less extent the Cartersville formation are associated with the ore deposits.

## STRUCTURE

The structure of the Valley and Ridge province in the Cartersville district is characterized by tightly compressed folds, prevailing easterly and southeasterly dips, and numerous thrust faults of varying magnitude. The overthrusting in nearly all observable faults has been from southeast to northwest, so as to give many reversals to the normal sequence. The folds strike in a general northeasterly direction.

The details of folding in the metamorphic rocks of the Piedmont are not known, as it is only in a few places that the bedding is observable and in still fewer that the original attitude can be determined.

The dominating structural feature of the area is the Cartersville overthrust, which separates the metamorphic rocks of the Blue Ridge and Piedmont provinces from the slightly metamorphosed rocks of the Valley and Ridge province. North and south of the Cartersville district this fault is a single break with




GEOLOGIC MAP AND SECTIONS OF THE CARTERSVILLE REGION, GEORGIA

Geology by G. W. Crickmay, in part after L. LaForge.

very low dip and considerable displacement. In the region under discussion, however, the fault has an apparent high dip and has associated with it an imbricate zone of minor thrusts. These minor thrusts cut across limestones and quartzites, and in these places wide breccia zones have been developed.

### SURFICIAL DEPOSITS

Loose unconsolidated deposits of recent origin are of particular importance in regard to mineral occurrences in this district. Their material is extremely variable in character, consisting of clay of various colors, of sand and waterworn gravel, of angular blocks of quartzite, and of mixtures of all three. The material, even the waterworn gravel, has commonly a steep dip, and in the clay beds complicated folds and faults on a minute scale may be observed. These structural features have been produced by slumping under the action of gravity on the steep hillsides.

The origin of these deposits is diverse—some are definitely colluvial, and others are alluvial. The clay is to some extent residual, but there is ample evidence to show that most of the material has been transported to its present position. Solution and residual weathering of the Shady limestone may have played an important part in the formation of the deposits. Where they occur in areas of quartzite, landslides and talus material have contributed to their accumulation. The greater part of the manganese and barite mined in the Cartersville district has been obtained from these heterogeneous mixtures of clay and gravel.

## ECONOMIC GEOLOGY

The minerals of commercial importance in the Cartersville district include pyrolusite, psilomelane, manganite, limonite, ocher, and barite. All these minerals may be found together, although in any one mine usually only one is present in quantity sufficient for profitable mining. Manganese and iron are most abundant north of Cartersville; barite and ocher are most abundant south of Cartersville. The manganese oxides most commonly occur with limonite—in fact, all variations from nearly pure manganese ore to equally pure limonite ore may be found. Their intimate association points to a common mode of origin. Barite is most commonly associated with ocher, and in places both are mined in the same open cut.

There are two distinct types of ore bodies—those occurring in bedrock and those occurring in loose unconsolidated clay and gravel. The ore deposits of manganese and barite are almost entirely confined to the clay and gravel; limonite and ocher have been mined only from bedrock.

## MANGANESE AND IRON

### Bedrock Deposits

The ores found in bedrock consist of limonite, in part manganiferous, though nowhere is the manganese content sufficiently high for the mining of manganese alone. In this group belong the Sugar Hill, Iron Hill, and Red Mountain mines. The deposits occur almost entirely in quartzite, not restricted to any particular horizon but scattered through both the Weisner and the pre-Cambrian quartzite. The ore is found most commonly in breccias, filling in the interstices and partly replacing the fragments of quartzite. (See fig. 36.) It also occurs as veins along

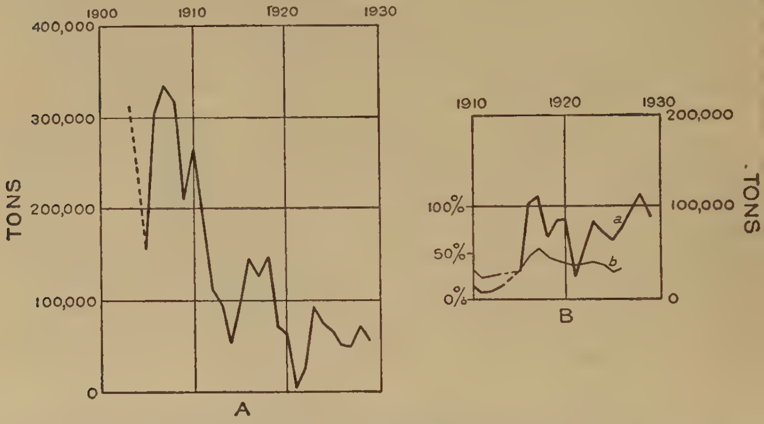



Figure 35.—Production of iron ore (A) and barite (B) in Georgia, 1903–1930. a, Total production of barite in United States; b, ratio of production in Georgia to total

joints and planes of stratification (Sugar Hill) and schistosity (Iron Hill).

### Surficial Deposits

The principal deposits of manganese occur in recent sand, gravel, and clay situated on the side or at the base of quartzite ridges. (See fig. 37.) In this class belong the Aubrey mines (fig. 38) and the Dobbins and Ziegler properties. There is no conformity in altitude of the mines and no correlation with old erosion surfaces.[1]

[1] LaForge (1919, p. 67) was of the opinion that most of the mines lay near or directly beneath the Highland Rim peneplain, although he recognized that some were far below that level.

There are three modes of occurrence of manganese oxides—(1) boulders of manganese oxide in gravel, evidently derived directly from the quartzite, for most of the gravel is quartzite and some of the manganese boulders have fragments of quartzite in them; (2) hard concretionary masses made up of concentric layers of psilomelane and manganite; (3) soft "chemical" ore, so called on account of its purity, which occurs in veins and irregular bodies in both clay and gravel.

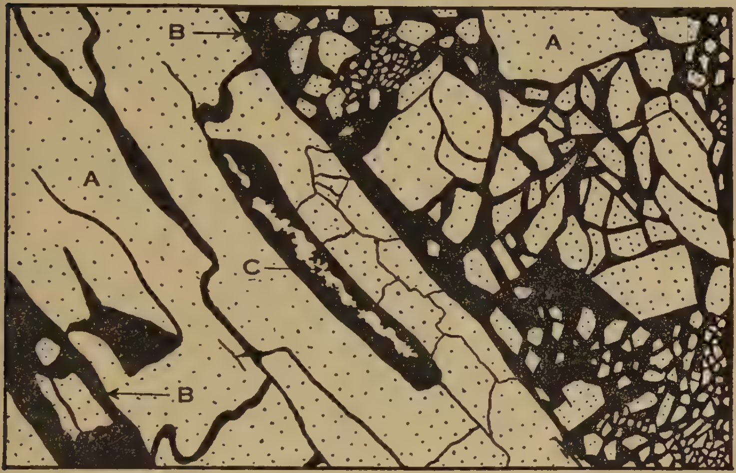



FIGURE 36.—Brecciated quartzite from Wolfpen Gap, Georgia. A, Quartzite; B, manganiferous limonite; C, open space with mammillary incrustations of oxides

## MINE DESCRIPTIONS

*Manganese Corporation of America* (No. 1, pl. 12).—This company owns much of the known manganese-bearing area northeast of Cartersville, but its recent explorations have been largely confined to a tract 4,000 feet (1,219 meters) long and 1,000 feet (305 meters) wide at Aubrey, 1¼ miles (2 kilometers) south of White. Within this area manganese has been mined from eight open cuts from 200 to 400 feet (61 to 122 meters) wide, 300 to 800 feet (91 to 244 meters) long, and 60 to 140 feet (18 to 43 meters) deep. After several attempts to mine by steam shovel, the use of hydraulic jets under high pressure was adopted. The surface near the open cut lies at an altitude of 900 feet (274 meters).

The Aubrey mines are situated in an area underlain by the Weisner quartzite and Shady limestone, but the areal distri-

bution of these formations is concealed by a covering of clay and gravel in which the manganese oxides occur. In three of the open cuts mining has revealed large rounded masses of fresh quartz-bearing dolomite (Shady formation). The trend of bedding in these blocks is diverse, and it is not clear whether they are true bedrock or isolated blocks.

In most of the explored area the manganese-bearing clay is covered by rudely stratified clay, sand, and gravel that generally contain little manganese. The thickness of this overburden varies from place to place and attains a maximum of 30 feet (9 meters) in Bufford No. 7 cut. Although manganese-bearing clay forms large masses, these do not have simple form and do

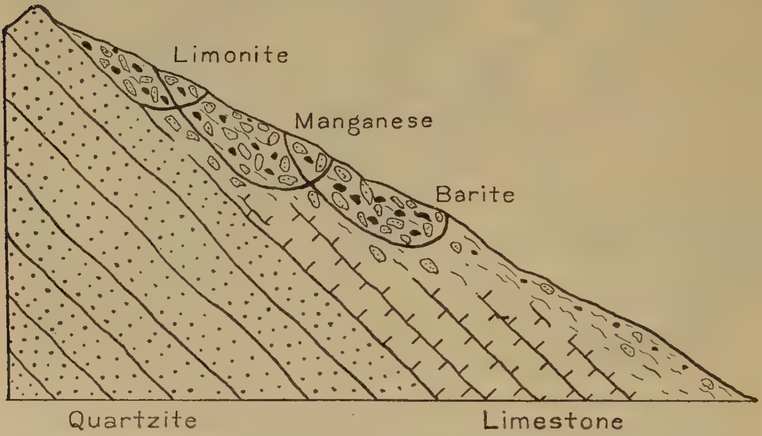



FIGURE 37.—Ideal section showing hillside relations of limonite, manganese, and barite in the Cartersville region. (After Hull, La Forge, and Crane)

not persistently underlie large areas. It is quite clear that these bodies of manganese-bearing clay lie within clay of somewhat similar character but differing in color and practically barren of manganese. The predominant manganese mineral is psilomelane, uniformly containing 6 to 8 per cent of barium oxide; it occurs largely as angular fragments. All the ore-bearing clay thus far mined contains subangular boulders of chert and quartzite. Some of the quartzite boulders are as much as 4 feet (1.2 meters) in diameter.

The material mined here is not the product of simple residual decay of the Shady dolomite. The subangular boulders of Weisner quartzite, now sporadically distributed through the clay, have been worn in surface streams, and the angular fragments of psilomelane have been broken in the process of trans-

portation from the site of their formation. The most reasonable hypothesis for the origin of these deposits is that the residual clays inclosing manganese oxides formed in the hills east of the area and have been moved by slumping to the place where they are now being mined.

A general description of the mining and milling plant, by M. T. Singleton, is given below.

The location of the present mining operations is on what is known as Big Spring Branch, a tributary to Pettit Creek. Below the junction of Big Spring Branch and Pettit Creek a dam impounds some 375,000,000 gallons (1,419,500,000 liters) of water, from which water is supplied for the mining and milling operations. Pumping capacity is provided for 12,000 gallons (45,425 liters) a minute.

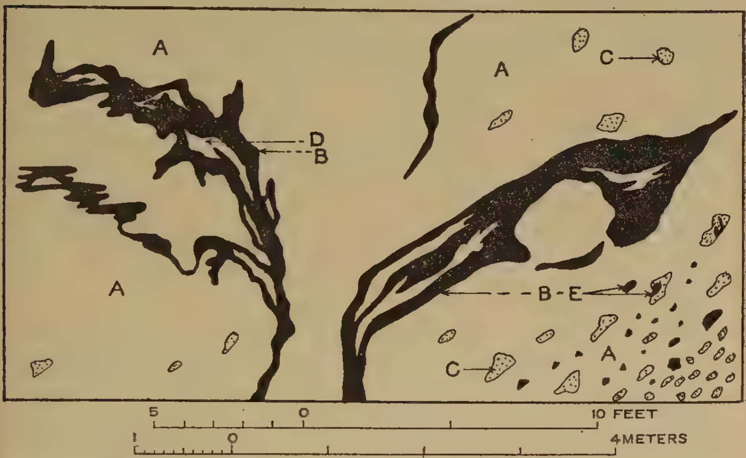



FIGURE 38.—Section in open cut at Aubrey, Georgia, showing mode of occurrence of manganese ore. A, Clay and sand; B, soft "chemical" manganese ore; C, rock fragments, mainly quartzite; D, white clay; E, hard nodular manganese ore

A 24-inch (0.6-meter) pipe line is laid from the Pettit Creek pumping station up through and beyond the mill and mining operations, terminating in a reservoir constructed by building an earth dam across Big Spring Branch. This upper reservoir floats on the line and provides a constant pumping head for the Pettit Creek pumps. It also provides considerable storage, which is available to the mining operations by gravity in case of an emergency.

At present there are two mining and washing units, known as the Bufford and Aubrey. Each unit consists of booster pumps which take their suction from the main line leading from the Pettit Creek reservoir to the Big Spring Branch reservoir and raise the pressure to about 200 pounds to the square inch (14 kilograms to the square centimeter) for hydraulic-giant operation. High-pressure lines extend from the booster pumps to the giants located in the mining pits. Four giants are usually operated in each area. The hydraulic giants disintegrate the bank clays and sluice the bank material to a sump, which is a steel drum covered with a perforated plate having 3½-inch (8.5-centimeter) openings.

At each sump there is a 6-inch (15-centimeter) dredge pump which pumps the material to a washing plant, discharging into a dewatering cone. The settleable solids are dewatered into the cone and discharged through the cone valve into a 25-foot (7.6-meter) Allis-Chalmers log washer. The burden on the log washer is light, the clay having been thoroughly disintegrated by the action of the hydraulic giants.

From the log washer the washed product, consisting of ore and gangue material, is discharged into cars. The overflow from the log washer and the overflow from the dewatering cone are both carried to a Dorr bowl classifier, which recovers all ore and sand down to about 200 mesh. The rake product of the classifier is discharged into cars with the washer product. The overflow from the classifiers is discharged into a mud pond.

The washer product and the Dorr bowl rake product from the two washing plants are hauled by cars to the concentrating mill, which is about half a mile (0.8 kilometer) from the washing plants. When the cars reach the concentrating mill, they are placed in a storage yard and, as needed, discharged into a track hopper having a capacity of about three cars. From the track hopper the ore is discharged by an apron feeder to a belt conveyor which conveys the ore to a ⅝-inch (1.25-centimeter) mesh scalping screen at the head of the mill. All screens are of the Traylor vibrating type. The oversize from the scalping screen is carried to a picking belt and then to a Symons cone crusher.

A water spray is kept on the cone crusher to assist in breaking up mud balls that come over on the picking belt. The crushed product drops into a small log washer, where such mud is washed out. A conveyor belt carries the crushed product back to the main conveyor, closing this circuit. The undersize from the scalping screen is passed over five additional vibrating screens, where five products are made for jigs, varying in size from ⅝ inch (1.25 centimeters) to larger than 14 mesh. The undersize from the last screen is pumped to a dewatering cone at the head of the table circuit.

The five jig sizes from the screens are discharged into feed bins, each having a capacity of about 20 tons, from which they are fed to five 3-cell Woodbury jigs. The cup products, or concentrates, from the first two cells of these jigs are dewatered and elevated into a concentrate loading bin at the shipping track. On the last cell of each jig an attempt is made to make a clean tailing, a middling product being taken from the cup. The middlings are returned by a belt conveyor to a set of crushing rolls; the roll product is discharged onto the belt conveyor, which carries the cone crusher product back to the main conveyor, thus closing this circuit.

The table feed, the undersize from the last screen pumped to a dewatering cone, is dewatered and fed to Fahrenwald classifiers, two classifiers being used in series to make 10 spigot products for 10 Deister tables. There are 4 classifiers and 20 tables in use.

Three products are made on the tables—concentrates, middlings, and tailings. The concentrates are pumped to a dewaterer discharging in the shipping bin; the tailings are dewatered with a drag dewaterer onto the tailing belt, and the middlings go to a drag dewaterer which discharges into a rod mill and are then pumped back to the dewatering cone at the head of the table circuit.

All water from the mill is carried to a settling pond, from which it can be recirculated to the mill, if desired. All water from the entire mining operation, after being discharged into the mud ponds, finds its way back into the lower Pettit Creek reservoir.

*Chumley Hill mine* (No. 2, pl. 12).—The Chumley Hill mine is situated on a small tributary of Pettit Creek. Considerable development work has been done in this area, but mining has long since been abandoned, and the open cuts are partly filled with débris from the sides.

The deposit is on the east side of the Cartersville fault in an area underlain by pre-Cambrian quartzite and graphitic phyllite. The quartzite is cut by many minor faults, and associated with these are prominent breccia zones. The strike of the formations is here N. 70°–75° E.

At the Chumley Hill mine manganiferous iron ore fills the interstices of a quartzite breccia and occurs in veins ramifying through unbrecciated quartzite. A high phosphorus content is a characteristic feature of this deposit.

*Dobbins property* (No. 3, pl. 12).—The Dobbins mine, on the west side of the Rowland Springs road about 4 miles (6.4 kilometers) northeast of Cartersville, is the oldest manganese mine in Georgia and probably the first producer of manganese in the United States (1866). Little can be seen in the old open cuts at the present time, as essentially all the ore is being mined underground. The mine is on the east slope of a ridge of Weisner quartzite. The ore occurs in unconsolidated clay and gravel, which are, to a large extent, detrital materials accumulated by hillside wash and talus. Soft "chemical" ore is found in pockets near the surface, but in depth the ore is hard and nodular and is associated with brecciated fragments of quartzite.

*Ziegler property* (No. 4, pl. 12).—The Ziegler mine is on the same ridge as the Dobbins property and about 2 miles (3.2 kilometers) south of it. The mine shows to advantage the character of the unconsolidated gravel in which the ore occurs. The pebbles are distinctly waterworn, and the gravel deposits dip at a high angle. The poor assortment and lack of imbrication suggest rapid accumulation. The ore occurs as boulders and as irregular nodular masses.

## ORIGIN OF THE MANGANESE AND IRON ORES

The source of the manganese of the region is obscure. In view of what is known of the relations of many deposits in eastern Tennessee and Virginia, the beds that mark the transition from the Weisner quartzite to the Shady dolomite seem the most probable source. From this source, most of the manganese has doubtless migrated appreciably before deposition as oxide. In some deposits, such as those near White mined by the Manganese Corporation of America, these oxides, as well as the inclosing clays, have moved considerably before reaching the places from which they are now mined.

The hillside colluvial deposits were thought by Hall, LaForge, and Crane (1919) to have been controlled by the specific gravity of the various components, so that a zonal distribution of

barite, manganese, and limonite was attained, as shown in Figure 37. These ideal relations are, however, not apparent in most of the area.

## BARITE

### Bedrock Deposits

The barite deposits in bedrock are of three types—(1) veins, most commonly present in the Shady limestone but also occurring in the Weisner quartzite and graphitic schist of the pre-Cambrian, together with fractures and cavities in the Weisner quartzite filled with acicular crystals of barite (Georgia Peruvian Co.); (2) replacement deposits in the Shady limestone; (3) deposits consisting of limestone breccia with barite as a matrix or of barite breccia with ocherous material as a matrix (Paga No. 1 mine).

### Surficial Deposits

The only commercial accumulations of barite are found in clay and gravel mainly of colluvial origin but also containing

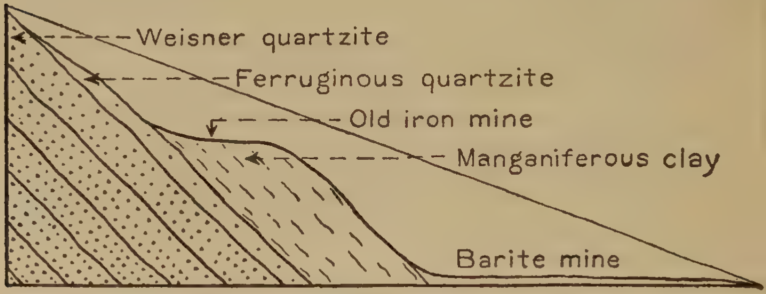



Figure 39.—Section through Nulsen barite mine, near Emerson, Georgia, showing geologic relations and typical sequence of ore overlying quartzite. (After Hull)

residual and alluvial material. The barite occurs as fragments derived from bedrock deposits—from a breccia deposit at the Paga No. 1 mine and probably from veins or replacement deposits at the Bertha mine.

### Mine Descriptions

*Nulsen mine* (No. 6, pl. 12).—The Nulsen mine, on the west side of the Dixie Highway about 1 mile (1.6 kilometers) north of Emerson, is the oldest operating barite mine in the State. The geologic structure is typical of almost all the barite mines. The only rock exposed in place is the Weisner quartzite, which forms the ridge to the west of the workings and strikes north and dips 45° E., thus forming the footwall of the deposit. (See fig. 39.)

*Paga No. 1 mine* (No. 8, pl. 12).—The Paga No. 1 mine is on the west side of a prominent ridge about 1 mile (1.6 kilometers) south of the Dixie Highway bridge across the Etowah River. The principal outcrops in the open cuts are the gray Shady limestone, which dips at a low angle to the west. The Weisner quartzite underlying the limestone makes up the main mass of the ridge to the east. In the area of limestone there is a breccia of barite with a matrix of ocherous material. The ore represents a residual accumulation from the breccia deposits.

*Bertha mine* (¼ mile (0.4 kilometer) east of No. 10, pl. 12).—The Bertha mine is on the north side of the Etowah River, 1¾ miles (2.8 kilometers) east of Cartersville and a quarter of a mile (0.4 kilometer) east of the New Riverside Ochre Co.'s mine. The property was originally worked for ocher and iron, but at present it constitutes one of the largest and richest deposits of barite in the area. The ore consists of barite fragments, commonly well rounded, inclosed in unconsolidated sand and gravel. The alluvial origin of some of the gravel is attested by the waterworn character of the quartzite and barite pebbles and the rude stratification that they present.

#### Origin of Barite Deposits

The barite deposits now being worked are quite evidently derived directly from bedrock deposits by processes of weathering and erosion, so that a consideration of the origin of the barite is concerned primarily with the deposits in bedrock.

Hayes, Phalen, and Hull believe that the primary barite deposition was effected by ascending thermal waters. Faults and widespread shattering of the rocks afforded easy passage for the mineralizing solutions. Hull suggested the barium-bearing feldspars and micas of the crystalline rocks as a possible source of the barium. The deposits of barite were formed by fracture filling and replacement in the Weisner quartzite and the Shady limestone.

### YELLOW OCHER

#### Bedrock Deposits

The ocher is confined to the quartzite and siliceous shales of the Weisner formation. It forms an irregular network of veins that penetrate the crushed and shattered quartzite in all directions. The veins have no well-defined margins but grade into slightly stained and unaltered quartzite.

### Surficial Deposits

The sandy clays in which the ocher is sometimes found are residual masses of Weisner quartzite, and the veins in them correspond in all essentials with the veins in the fresh rock. These deposits, which on account of their unconsolidated nature are the most easily mined and thus the most valuable, are truly residual and are quite distinct from the colluvial and alluvial material from which the manganese and barite are obtained.

### Mine Descriptions

*Georgia Peruvian Co.* (No. 7, pl. 12).—The property of the Georgia Peruvian Co. is a quarter of a mile (0.4 kilometer) south of the Dixie Highway bridge over the Etowah River. Most of the ore has been taken from underground workings that are now closed, but excellent surface outcrops may be seen in the open cuts. The shattered character of the quartzite and the irregularity of the veins is particularly evident. A noteworthy feature at the mine is the occurrence of beautiful crystals of barite in cavities in the quartzite.

*New Riverside Ochre Co.* (No. 10, pl. 12).—The property of the New Riverside Ochre Co. is a quarter of a mile (0.4 kilometer) west of the Bertha barite mine, on the north side of the Etowah River. The hills surrounding the mine consist of quartzite striking north and dipping steeply to the east. In the vicinity of the mine the quartzite is impregnated with ocher and weathered to a soft residual yellow clay.

### Origin

The ocher deposits were formed by replacement in shattered Weisner quartzite. Through subsequent weathering some of the ocher bodies have been inclosed in residual clays derived from the decay of the quartzite.

The iron oxide was probably derived in part from the decay of surface rocks and the downward migration of the iron in solution, and from the oxidation of pyrite, which is a widespread and abundant constituent of the quartzite. Hayes and Watson ascribe the deposition of the ocher to the principle that under certain conditions a carbonic acid solution of iron carbonate, meeting an oxidizing solution, precipitates the iron as ferric hydrate and at the same time dissolves silica.

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# THE DUCKTOWN MINING DISTRICT, TENNESSEE

By W. H. Emmons

ABSTRACT

The Ducktown mining district, in the southeast corner of Tennessee, is the largest producer of copper and sulphuric acid in the southern Appalachian region. The deposits were opened in 1847 and have been worked almost continuously since that date. Two companies are operating in the district—the Tennessee Copper Co. and the Ducktown Copper, Sulphur & Iron Co.

The country rock consists of schist and graywacke intruded by gabbro. A great group of granitic batholiths which extend the length of the southern Appalachian Mountains lies a few miles to the east, and the deposits are believed to have been formed in connection with the intrusion of the granite, probably near the end of the Paleozoic era.

The deposits are great lenses of heavy sulphide ore. They extend with interruptions for thousands of feet on the strike and are from 1 to 300 feet (0.3 to 91 meters) or more wide. Except where faulted they lie with the bedding of the schists and have the form of close folds; some of them are "saddle reefs." It is believed that they represent a limestone bed that was closely folded and extensively faulted and subsequently replaced by hot solutions that rose along faults and along the folded and faulted limestone bed.

At places the original bedded limestone is found in the ore zone, but nearly all of the limestone has been replaced by ore. The minerals include pyrrhotite, pyrite, chalcopyrite, magnetite, garnet, amphibole, and chlorite. The ore near the surface is altered to iron oxide or gossan, which extends to a depth of about 100 feet (30 meters); below the gossan at the water level is a zone of chalcocite from 3 to 8 feet (0.9 to 2.4 meters) wide which contains 5 to 25 per cent of copper, and below this is the primary copper ore now mined, which carries about 1 to 3 per cent of copper.

## INTRODUCTION

The Ducktown mining district (fig. 40) is in the heart of the southern Appalachian Mountains, in the southeast corner of Tennessee and the adjacent part of Georgia. It lies between 1,400 and 1,800 feet (427 to 549 meters) above sea level, in a basin that is surrounded by mountains that rise to altitudes of 3,000 feet (914 meters) or more. The basin has a mild climate, is well watered, and at one time supported a growth of pine timber, but the timber was removed for mining purposes. The sulphide ore was formerly roasted in open heaps, and the fumes killed the vegetation near the mines. Although heap roasting has been discontinued for about 25 years, the area is only partly regrown in grass. As a result there is vigorous erosion within the area, and the country within a radius of 2 or 3 miles (3.2 to 4.8

kilometers) has a desert aspect. (See pl. 13, *A*.) Within the basin is a population of about 8,000 people, who depend almost entirely upon the mines and the metallurgical and acid industries for support.

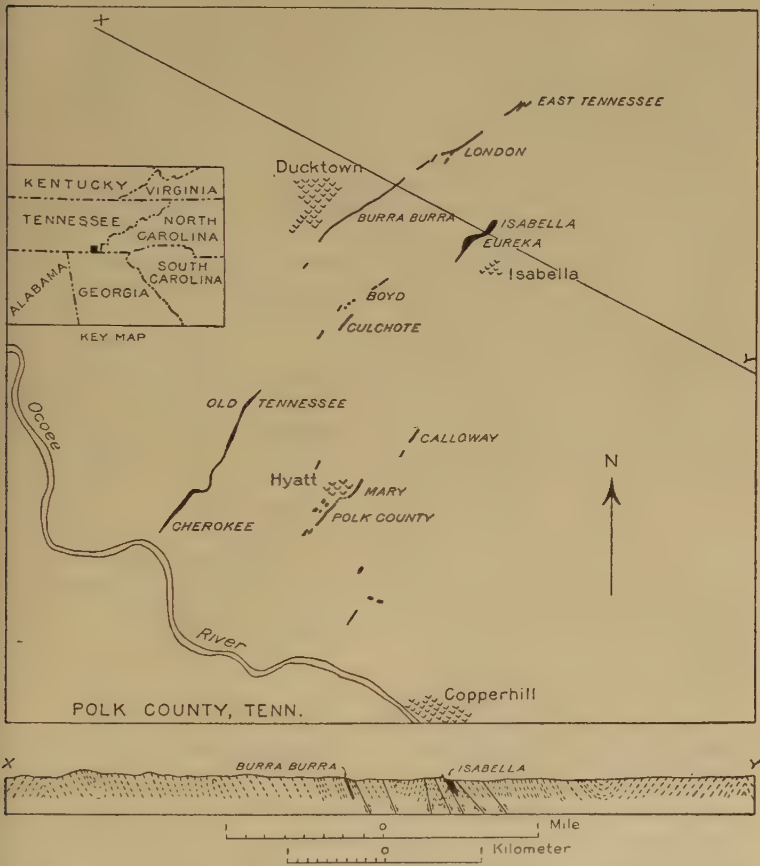


FIGURE 40.—Map and cross section of producing part of Ducktown district, Tennessee. The country rock consists of sandy mica schist and graywacke. The lodes (black) are heavy sulphide ores with about 1.5 per cent of copper. (From map by Emmons and Laney)

## GEOLOGY OF THE REGION

The Appalachian mountain system extends from Newfoundland southwestward to Alabama, a distance of 2,000 miles (3,219 kilometers). In this area the prevailing rocks are of pre-

Cambrian and Paleozoic age. They are closely folded and are intruded by granite. The width of the closely folded area is in places not less than 200 miles (322 kilometers). The folded area is overlapped unconformably on the southeast and south by Cretaceous rocks. On the west the area of closely folded Paleozoic and older rocks is bordered by a belt of Paleozoic rocks that are more gently folded, the folds gradually decreasing in amplitude to the northwest. The mountains are relatively low. In general the high peaks are less than 1 mile (1,610 meters) high although some of them rise above 6,000 feet (1,829 meters).

The great folds of the Appalachian region were formed during the Appalachian revolution near the end of the Paleozoic era (Hercynian). The country underwent erosion in Cretaceous time, and during or near the end of the Cretaceous period a peneplain was formed, which subsequently was uplifted and eroded. Many of the summits of the high mountains are believed to be the remnants of this ancient peneplain.

The chief ore deposits of the southern Appalachian region were formed during the later part of the Paleozoic era. They are believed to be connected with the intrusion of the granite, for the area containing the deposits is essentially the area intruded by the granite, although the mineralized area extends outward from the intruded area on each side of the great belt of granite outcrops. There is a rude zonal distribution of the ores. Gold and a little tin are found in the area of closely spaced granite intrusives. Copper ores are found west of the gold-bearing area, and deposits of lead and zinc ores lie west of the belt of copper ore. The Ducktown district is within the belt of copper ores. Other mines of this belt include the Fontana and Adams mines, in North Carolina.

## HISTORY AND PRODUCTION

The Ducktown mining district produces large amounts of sulphuric acid, copper, and iron ore (sinter) and small amounts of zinc concentrates and precious metals. It ranks first among the Appalachian fields in the production of acid and copper. The district takes its name from Duck, a Cherokee chief who once held sway in its vicinity. It has been stated that the Indians prior to the coming of the white man utilized the Ducktown ores and smelted them in a crude way for copper, but this is probably erroneous, for no ancient workings have been found in the region. A prospector named Lemmons discovered the outcrop of the Burra Burra lode in 1843, but no exploration was undertaken until 1847, when A. J. Weaver obtained a lease and shipped to the Revere smelting works, near Boston, 31,000 pounds (14,061 kilograms) of ore that carried 25 per cent of

copper. Soon afterward the area was actively prospected, and rich secondary ore was found in nearly all the lodes that are now worked. Several small smelters were built, and the copper was hauled by wagon about 40 miles (64 kilometers) to the railroad at Cleveland, Tennessee. A railroad was built through the Ducktown district about 1890, and since that time the district has been developed on a modern scale. The annual production of copper in recent years has been between 15,000,000 and 20,000,000 pounds (6,804,000 and 9,072,000 kilograms).

The mines in the district are situated at Ducktown, Hyatt, and Isabella. They are operated by the Tennessee Copper Co., with headquarters at Copperhill, and the Ducktown Copper, Sulphur & Iron Co., with headquarters at Isabella. Both companies operate mines, concentrating plants, roasters, smelters, converters, acid plants, sintering plants, and railways. The method of treatment is essentially similar in both groups. Some of the ore is smelted directly, and some of it is concentrated by oil flotation. The iron concentrates are roasted, and the roasted iron is sintered and shipped to southern iron furnaces. The blister copper is sent to eastern refineries. The acid is used chiefly for making phosphate fertilizer. Both companies use the chamber method of making acid, and at Isabella a plant has recently been built utilizing the contact process.

## MINING METHODS

The ore bodies of the Ducktown district are from a few feet to 300 feet (91 meters) or more in width. The ground stands well, and it is not necessary to use much timber. The method of mining depends mainly upon the width of the ore body. A few years ago the practice of sublevel underhand stoping was introduced in parts of certain mines. At present this method is in operation in the Burra Burra mine.

In sublevel stoping four sublevels are driven between the main haulage levels, which are 200 feet (61 meters) apart. Where the ore body is not more than 40 feet (12 meters) wide the sublevel stopes are run with the vein the full width of the ore. Raises are run on the footwall, and the sublevels are run from these raises. Raises or pull holes are run upward into the ore from the haulage level. These are about 40 feet (12 meters) apart. The ore from the sublevels is drilled by down holes and is blasted off from benches and drops directly into pull holes, where it is loaded into cars by gravity. The benches in the sublevels are mined by receding from the pull holes in series in such a way that the roof above the workmen may always be tested by a 15-foot (4.5 meter) bar. In this way the miners

are always working below a safe roof, and accidents due to fall of rock are practically eliminated. Where the ore body is more than 40 feet (12 meters) wide the same method is employed, but the stopes are run in panels across the veins. These are 40 feet wide, and between them are 40-foot pillars which later are removed. In 1928 the average of ore broken per drill-man shift was 48 tons (43 metric tons), and the average per man-shift put through the grizzlies was 72.5 tons (65.7 metric tons).

## GEOLOGY OF THE DISTRICT

The prevailing rocks of the Ducktown district are sandy schists and graywackes, with which are interbedded mica schists. The rocks are all included in the Great Smoky formation, which is the metamorphosed product of Cambrian conglomerates, grits, sandstones, and shales. The beds grade into one another along the strike and across the bedding. They contain small bodies of pegmatite and peculiar masses and stringers of an actinolite-feldspar rock which has a composition near that of quartz diorite (pl. 13, *B*), but which has been developed by metamorphism from material of sedimentary origin. The schists are cut by dikes of gabbro, which are not so highly metamorphosed by pressure as the sedimentary beds. The schistosity and bedding of the sedimentary rocks nearly everywhere strike northeast, and the prevailing dip is southeast. The rocks are folded into sharp folds, many of them isoclines. Many of the folds are broken along the crests, and they pass into strike faults that nearly everywhere dip southeast. (See fig. 40.) A few cross faults of small throw are found in the underground workings.

## ORE DEPOSITS

The ore deposits of the Ducktown district were formed by the replacement of limestone lenses that were probably originally deposited at a single stratigraphic horizon. Anticlines and faulted anticlines, which are characteristic of the country rock of the region, are shown also in the ore deposits. The ores themselves are somewhat metamorphosed by dynamic processes and the gangue minerals are bent, but at most places they do not show a well-defined schistosity. They were deposited later than the rocks that now inclose them and after the limestone they replace had been subjected to considerable dynamic metamorphism.

*Structural relations.*—The ore deposits are clearly bedding-plane deposits, for they show all the structural features of the rocks that inclose them. At many places staurolite schist lies just above the ore. At several places underground remnants

*A.* RECENT EROSION IN THE DUCKTOWN DISTRICT, TENNESSEE
From U. S. Geol. Survey Prof. Paper 139, 1930.

*B.* NODULE OF PSEUDODIORITE IN GRAYWACKE
From U. S. Geol. Survey Prof. Paper 139, 1930.

of unreplaced limestone are found recrystallized to marble. Before the limestone lenses were replaced they were closely folded and intensely faulted, and many of the faults cut locally across the beds, so that the ore which subsequently replaced the limestone seems to cut across the beds. Persistent faults follow nearly all the lodes, and some of them cut the schists at small angles. Thus the ore deposits that replaced the limestone along these faults locally lie at small angles to the beds. This relation is best observed near the main deposit of the Burra Burra mine (figs. 41, 42), where the highly folded schists strike more nearly north than the Burra Burra lode. In places underground the borders of the lodes make angles as high as 30° with the schist wall rock, but these are of very local occurrence, and all of them are along faults.

*Mineralogy of the ores.*—The outcrops of the lodes are composed of iron oxide and quartz and contrast strongly with the country rock. Most of this gossan has been removed and shipped to iron furnaces. The water level is generally from 20 to 100 feet (6 to 30 meters) deep. There was a zone of rich secondary ore having a vertical extent of 3 to 8 feet (0.9 to 2.4 meters) at the water level. This ore, which carried from 5 to 25 per cent of copper, was composed of chalcocite, bornite, copper sulphate, and residuary pyrite, quartz, and silicates. Below the rich secondary ore is the primary ore, consisting of pyrrhotite, pyrite, chalcopyrite, zinc blende, bornite, specularite, magnetite, actinolite, tremolite, calcite, quartz, pyroxene, garnet, zoisite, chlorite, graphite, and feldspars. Essentially the same minerals are found in all the deposits, but they appear in varying proportions at different places in the lodes. Where the copper content is about 1.5 per cent or where the sulphur and iron contents are high this material is ore; but where the proportion of actinolite and other silicates is greater and the sulphides are less abundant the material is not workable. The average tenor of smelting ore is about 1.5 per cent copper. Ores as low as 1 per cent copper but high in iron sulphides are mined to obtain a gas high in sulphur dioxide when there is good demand for acid. Much of the ore contains large fragments of schist and graywacke.

*Type of mineralization.*—The association of minerals is one that is commonly developed by contact-metamorphic processes or in hypothermal lodes. The deposits, however, do not lie along contacts with igneous rocks, although they are near the intruding gabbros, and about 12 miles (19 kilometers) to the southeast granites intrude rocks as late in age as the ore-bearing series at Ducktown.

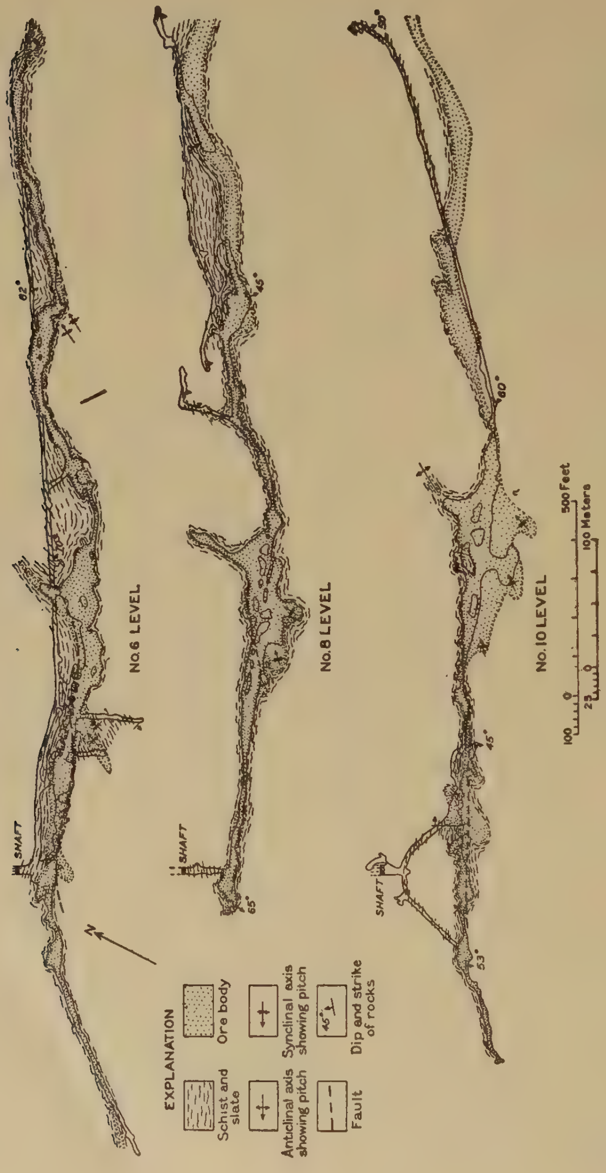


FIGURE 41.—Plans of levels 6, 8, and 10 of Burra Burra mine, Ducktown district. (After Emmons, W. H., U. S. Geol. Survey Prof. Paper 139, pl. 26, 1926)

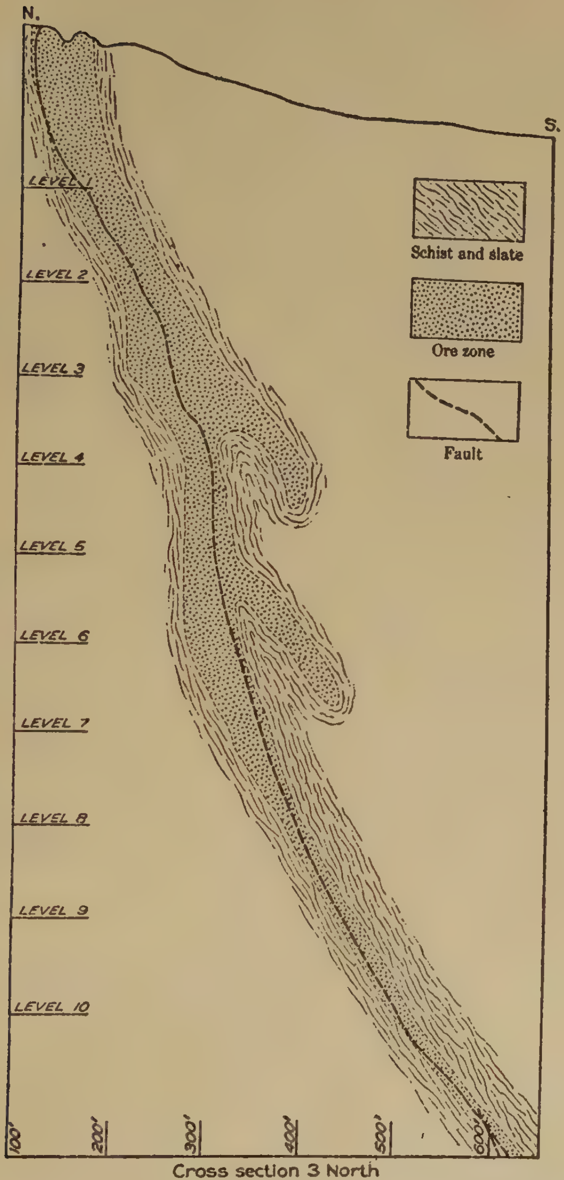


FIGURE 42.—Vertical cross section of Burra Burra mine, Ducktown district. (From U. S. Geol. Survey Prof. Paper 139, pl. 28, 1926)

*Genesis of deposits.*—The genesis of the Ducktown ores is believed to be as follows: A thin bed of limestone, now almost completely replaced by ore, was present in the series of feldspathic sandstones and clays that were subsequently converted into the graywacke, shale, and schist. Probably this limestone bed was not continuous, but its areal extent is not known. The structure of the region is domelike. The central portion of the district is a well-defined dome, greatly elongated along the northeast-southwest axis. Extensive faulting and close folding have brought to the surface the lower members of the Great Smoky formation. Possibly the limestone was much more extensive than is indicated by the distribution of the ores, but if so it has either been removed by erosion or is buried under later rocks in the region surrounding the mineralized area. Owing to the deformation which the limestone has suffered its original thickness can not be estimated, but from the size and structure of the ore bodies by which it has been replaced it appears probable that the limestone was originally not more than 50 feet (15 meters) thick, possibly less. Because of the deformation of the limestone, its thickness in places was increased and the ore bodies that replaced it are locally much thicker.

After the Great Smoky formation had been deposited, it was buried, probably under many thousand feet of later sediments. Subsequently it was folded, faulted, and deformed by pressure. The feldspathic sand was converted into graywacke, the clay into slate and schist, and the limestone into marble. The form of the thin limestone bed or lenses, with heavy sandy beds on each side, was greatly changed when it was subjected to deformation by folding. At some places the limestone was eliminated entirely, and the sandy walls came together; at other places the thickness was greatly increased by folding and faulting. The most notable increases are along the crests of anticlines or at anticlinoria where several folds are developed and in troughs or minor synclines. The yielding limestone associated with the stronger sandy rocks was readily deformed and assumed various forms. During the folding and possibly also after the principal period of folding the rocks were extensively faulted. Small masses of limestone were dragged along the faults, and subsequently these were replaced, forming small bodies of ore that are now exposed here and there along some of the faults. At some places near the ore zone where openings were available small calcite veins were formed by the migration of calcium carbonate from the limestone bed into the schist walls.

The schist was broken during faulting, and the fragments were incorporated into fault breccias. Where faults crossed the limestone bed some of these fragments were carried along the fault

into the limestone. Thus blocks of schist, some of them of great size and rounded by movement, were dragged into and became surrounded by calcareous material, which, when recrystallized, formed the matrix of the breccia. After the period of most profound metamorphism and deformation the calcareous beds, calcite veinlets that made off from them, and the calcareous material that had been dragged along the faults were replaced by ore, quartz, and the heavy silicates with which the ore minerals are associated. The chemical changes of limestone to ore are closely similar to those that commonly take place where limestone is changed to heavy silicate rocks by contact metamorphism, and this suggests magmatic waters as agents of replacement, but the source of the mineralizing solutions is not known. The mineralization and other alterations at the time the ores were deposited were not confined to the calcareous rocks. The graywacke and schist were locally somewhat altered, and boulders of graywacke and schist were altered profoundly.

## ITINERARY

*Surface features of the district.*—At Hyatt, where the Mary and Polk County mines are located, the country rock is well exposed and the outcrops of the ore deposits may be seen. South of the Polk County shaft there are good exposures of the staurolite schist which is commonly found along the ore zone. The anticlinal structure of the Mary mine (fig. 43) may be seen in a cave where the roof has fallen into the stopes of the mine. This deposit does not crop out near the caved stopes. The schist of the hanging wall covers the sharply folded anticlinal ore body so that it does not extend to the surface. This is well shown in the walls of the caved area. Westward from Hyatt the great gossan pits of the Old Tennessee mine may be seen.

*Isabella and Eureka open pits.*—Here the gossan iron ore and the primary sulphide ore may be studied and the position of the secondary copper ore may be noted. The Eureka and Isabella open pits coincide approximately with the area of the outcrop of the gossan ore before the gossan was removed for iron ore. The combined open cut is about 1,500 feet (457 meters) long and 100 to 250 (30 to 76 meters) wide. Below the gossan is a great deposit of sulphide ore, which is high in sulphur and iron and relatively low in copper. Structurally the deposit is an elongated faulted and overturned dome. The country rock is schist and graywacke. Staurolite schist is exposed on both sides of the ore body at the southwest end and is believed to be the same bed. The ore body is faulted in places on the northwest and southeast sides. At the northeast end of the pit the ore dips to the southeast, and at the southwest end it dips to the northwest.

*Outcrop at the Burra Burra mine.*—This outcrop is followed for 3,000 feet (914 meters) along the strike. For much of this distance the outcrop was marked by iron oxide or gossan ore, which was removed and shipped to various southern smelters. Later the walls were allowed to cave and were blasted down for filling underground, so that a great cave now marks the outcrop. The strike of the outcrop is N. 55° E., and the dip near the surface is about 72° SE. The country rock is graywacke that

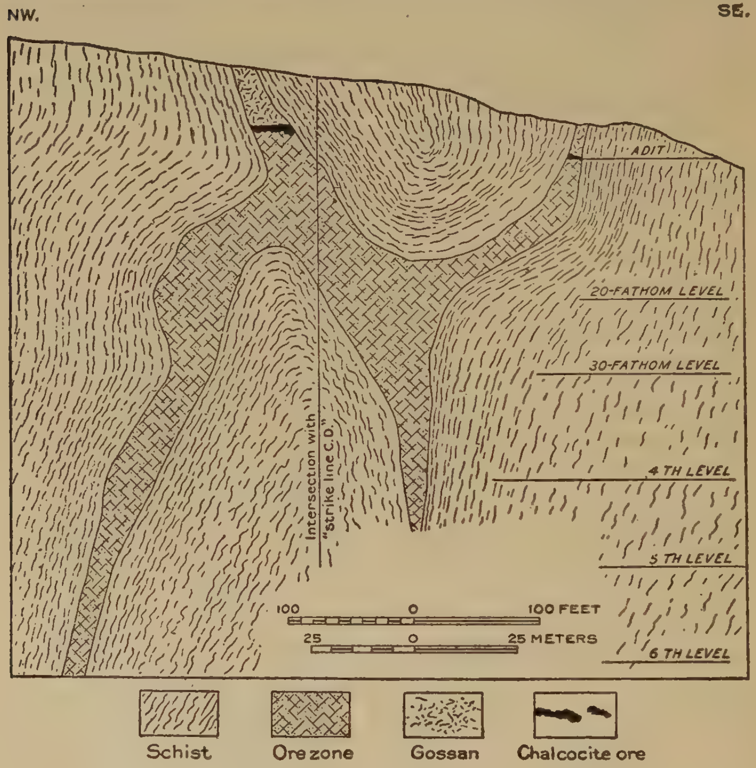


FIGURE 43.—Cross section of Mary mine, Ducktown district

includes beds of mica schist or slate. The bedding of the schist is in general parallel to the lode, but at places, notably on the hanging wall of the lode southwest of the Burra Burra shaft, the schist strikes N. 35° E. and makes an angle of 20° with the strike of the lode. This difference in strike may be noted also underground and is due to faulting along the lode and to small folds in the lode that plunge steeply to the northeast, making small angles with the general strike of the lode.

*Underground workings of the Burra Burra mine* (fig. 41).—The deposit is opened for about 3,000 feet (914 meters) along the strike and to a depth of 1,800 feet (549 meters). The general strike is N. 55° E., and the dip near the surface is 72° SE., but underground the dip becomes lower, and at the bottom of the mine it is about 55°. A great fault extends the entire length of the Burra Burra lode. Evidence of this is found in the great breccias that are exposed at many places underground. These breccias are cemented by ore, and the fragments of the wall rock in the lode are in part replaced by sulphides, showing that the major faulting preceded the deposition of the ore. The walls of the ore body are very irregular. Small folds are developed on both hanging wall and footwall, and except where there is displacement by faulting the contact of ore and country rock is parallel to the bedding of the country rock. As a result of faulting and folding the width of the ore body varies from less than 1 foot (0.3 meter) to more than 200 feet (61 meters). Where the replaced bed is thin it is partly faulted out; where it is thick it is reduplicated by folding. As seen by Figure 41, there is a very wide section of the veins on level 10. This is due to close packing of folds which may be followed from a point near the surface to the bottom of the mine. These folds make out chiefly into the hanging wall, but one of them, called the West vein, branches off from the footwall of the main lode. It is followed from the surface to level 18 and is shown in Figure 41. It is noteworthy that the schist near this branch of the deposit changes its strike so that it lies parallel to the west branch, as shown in level 8. (See fig. 41.) The same movements that involved the schists involved also the bed that was replaced by ore.

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# THE MASCOT-JEFFERSON CITY ZINC DISTRICT OF TENNESSEE

By Mark H. Newman

ABSTRACT

The Mascot-Jefferson City district is situated in Knox and Jefferson Counties, in Eastern Tessessee, in the valley region of the southern Appalachians.

The formations are all sedimentary, no igneous rocks having been found in the district. The outstanding structural features of the valley are folds and overthrust faults, which have resulted in duplications of the formations into bands with northeasterly trends. The mines at Mascot and at Jefferson City are in one of the bands. The zinc deposits are associated with a series of limestone beds within the Knox dolomite, which is of Cambrian and Ordovician age and is approximately 3,000 feet (914 meters) thick.

Sphalerite is the sole primary ore mineral. Oxidation of the sulphide has resulted in some commercial bodies of carbonate and silicate ores. The primary ore bodies commonly occur in breccias that parallel the bedding. The breccias are both shatter and rubble breccias.

At Mascot the ore bodies follow sinuous courses and tend to interconnect. At Jefferson City mining developments are not extensive enough to determine whether similar relations exist. No change in character of ore or in mineral association has been observed at Mascot to a depth of 1,000 feet (305 meters) vertically.

## INTRODUCTION

The Mascot district, 13 miles northeast of Knoxville, Tennessee, and the Jefferson City district, 16 miles northeast of Mascot, are notable producers of zinc ore. They are especially interesting as offering problems concerning the structural relations and origin of the deposits on which there is as yet no general agreement.

Grateful acknowledgment of assistance in the preparation of this description of the district is made to Walter F. Pond, State geologist of Tennessee; to Messrs. Ellis, Weed, and Crawford, of the Universal Exploration Co., and to Mr. Coy, of the American Zinc Co., of Tennessee.

The latest and most comprehensive account of the zinc deposits is that by Mark H. Secrist (Zinc deposits of east Tennessee: Tennessee Geol. Survey Bull. 31, 1924), which refers to and summarizes the earlier literature.

## GEOGRAPHY

The district is in the southwesterly extension of the Shenandoah Valley and the Valley of Virginia. The valley here is about 50 miles (80 kilometers) wide and has the Cumberland Plateau on its northwest and the Great Smoky Mountains on its southeast side. Topographically it is a country of sharp ridges with relatively narrow intervening valleys. The ridges are formed of resistant sandstone and chert, the valleys of less resistant limestone and shale. The ridges are mostly wooded; the valleys are largely agricultural and grazing land.

The region has short and mild winters, not too hot summers, and bountiful rainfall. Tree and vegetal growth is vigorous. The valley soils derived from limestone and those formed by alluvial material along streams are deep and fertile. They are extensively cultivated. In areas underlain by shale the soils are less desirable and not so commonly farmed. The principal crops are corn, wheat, and tobacco. Woods include both hard and soft varieties. The principal occupations are farming and manufacturing, including textiles, clothing, iron and steel products, furniture and lumber, and marble. The district is drained by the Holston, Powell, and Cumberland Rivers, all tributaries of the Tennessee River.

Knoxville, the largest near-by city, has a population of over 105,000. The population is largely native born.

## HISTORY

Zinc ore mining in the Great Valley of eastern Tennessee dates back to the middle of the last century. Outcrops of both oxidized and sulphide ore occur at many places. Where conditions were favorable carbonate ores have been concentrated at the outcrop, and the early production was largely derived from such ores.

The largest output of oxidized ores has probably come from the Embreeville district, which has produced both lead and zinc. In the Mascot-Jefferson City district a large body of oxidized zinc ore near Jefferson City known as the Grasselli carbonate mine was worked until 1913. The Universal Exploration Co., a subsidiary of the United States Steel Corporation, has developed a body of oxidized zinc ore in the Maples mine at Jefferson City that will probably prove to be one of the larger of that type in Tennessee. Shipments of ore were started in 1928.

Tennessee first came to general attention as a possible major producer of zinc ore in 1913, when the Embree Iron Co. shipped

its first oxidized ores from Embreeville and the American Zinc Co. its first sulphide concentrates from Mascot. The latter shipment marked the beginning of large-scale mining of low-grade sulphide ores. In 1929 the American Zinc Co. shipped its first crude ore from its Jarnigan mine, at Jefferson City, to Mascot for concentration. Subsequent to 1913 the Grasselli Chemical Co. prospected the sulphide ores at its carbonate mine and carried their development to the point of mining, though actual mining has not yet been undertaken. In 1930 the Universal Exploration Co. milled sulphide ores from its newly developed Davis mine at Jefferson City. (See fig. 44.)

## GENERAL GEOLOGY

The formations in this part of the Great Valley are limestones, shales, and sandstones ranging in age from Cambrian to Carboniferous. (See fig. 45.)

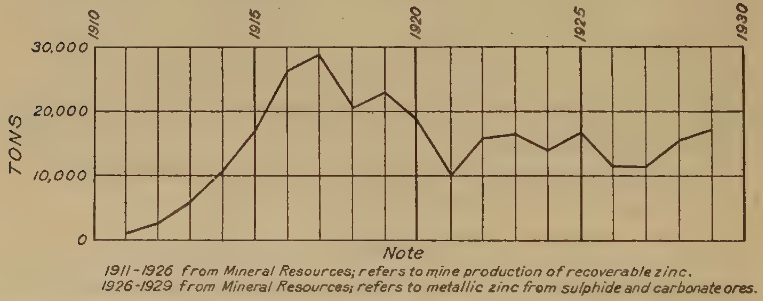


FIGURE 44.—Production of zinc in Tennessee, in short tons of recoverable zinc, 1911–1929

The strata underlying the valley have been intensely faulted and folded. The folds and faults are parallel to one another and to the northeasterly trend of the valley. Faults 300 miles (482 kilometers) long and folds of even greater length are known. Many of the folds have been so far compressed that their sides are parallel. The prevailing dips are to the southeast. Faults were developed in the northwestern limbs of anticlines, and the fault planes dip at low angles toward the southeast, approximately parallel to the bedding planes of the strata on the southeast limb. The displacement along these overthrust planes amounts to as much as 6 or 8 miles (9.6 to 12.8 kilometers) or more.

The folding and faulting have distributed the formations into more or less separate parallel bands that ribbon the country in a northeasterly direction. The same formations crop out repeatedly across the valley.

*Knox dolomite.*—The Knox dolomite, of Cambrian and Ordovician age, contains most of the valuable zinc deposits of the valley province of Tennessee. It is composed mainly of dolomite or dolomitic limestone but includes interbedded limestone, some sandstone, and at some horizons an abundance of chert. It has a thickness of 3,000 feet (914 meters) or more. Overlying the Knox is the Mosheim formation, comprising 50 feet (15 meters) of relatively pure limestone. Faulting has produced seven separate bands of Knox dolomite strata paralleling the northeasterly trend of the valley. The Mascot-Jefferson City district lies in one of these bands.

Zinc ores occur at several horizons in the Knox dolomite. East of Dandridge, 12 miles (19 kilometers) southeast of Jefferson City, the ores are near the top. At New Prospect, 25 miles (40 kilometers) northwest of Mascot, ore deposition took place near the base of the formation. The horizon of the most productive ores is at approximately the base of the upper third of the Knox, about 800 to 1,000 feet (244 to 305 meters) below the top. The Mascot and Jefferson City ore bodies are at this intermediate horizon, as is also the mineralization in the adjacent and parallel Copper Ridge band of Knox strata, to the northwest.

The intermediate horizon is marked by a series of limestone beds, called "brown lime" at Mascot and "dove lime" at Jefferson City. These beds are brown in the mines and dove-colored in the outcrops. Somewhat similar beds occur in other parts of the Knox strata, but the terms "brown" and "dove" are applied only to the beds at this horizon. The terms are descriptive of the color of the rock only and have no significance with respect to the mineralization. Between these limestone beds and the Mosheim limestone, above the Knox, only a few thin limestone beds are intercalated in the dolomite.

At Mascot the "brown limestone" horizon is 150 to 200 feet (46 to 76 meters) or more thick. Within it dolomite predominates. It includes six or seven limestone beds whose aggregate thickness represents 10 to 20 per cent of the total. Some of the limestone beds appear to thin out within relatively short distances, and they seem to overlap. At Jefferson City the limestone beds are thicker than at Mascot, one bed having a thickness of over 50 feet (15 meters). In the mineralized areas at Mascot the limestone has been dolomitized, so that not much limestone is encountered in the mines.

## ORE BODIES

Mineralization has taken place in brecciated beds of the limestone horizon. The ore deposits are not coextensive with the ore-bearing strata but are generally large both in cross

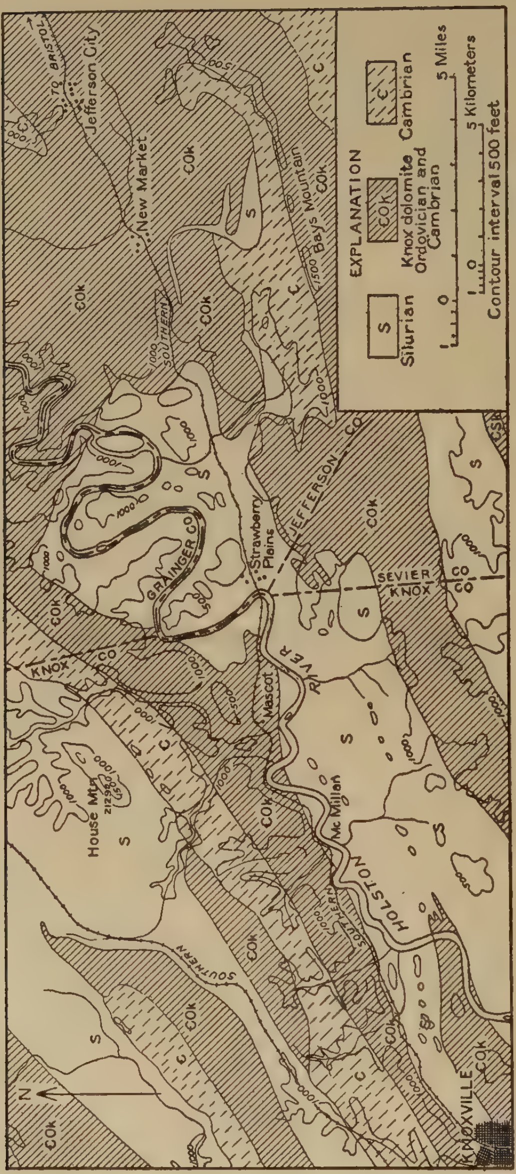


FIGURE 45.—Geologic map of region between Knoxville and Jefferson City, Tennessee

section and in length. Their outlines are irregular, and ore shoots follow winding and sinuous courses. The extensive developments at Mascot show that many of the ore bodies are connected and tend to form a network inclosing intervening unmineralized areas. (See fig. 46.) The developments at Jefferson City are not sufficiently advanced to show whether a similar distribution of ore exists there.

The bottom of the ore at Mascot is almost invariably one of the altered brown limestone beds (fig. 47), though not always the same bed in every part of an ore body. This difference

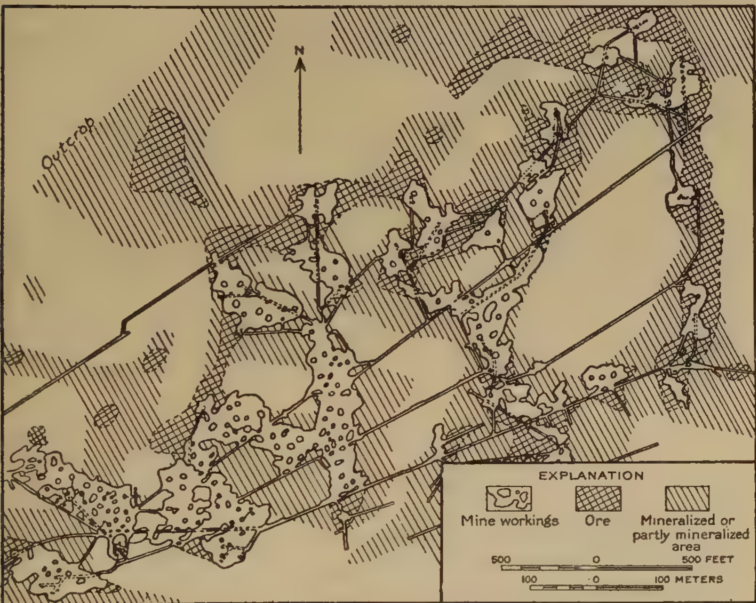


FIGURE 46.—Map of part of workings of mine No. 2, Mascot, Tennessee, showing distribution and connection of ore bodies

appears to be due to a selective change of horizon and not to displacement of the beds. The limestone where dolomitized and marbleized is called "recrystalline" and, where an ore, is usually of higher than average grade. At Jefferson City flint in places underlies the lowest "recrystalline" bed of the ore body.

The top and sides of the Mascot ore shoots are determined only by the zinc content. This ordinarily terminates rather abruptly at the sides but decreases more gradually at the top. At Jefferson City the zinc is cut off more abruptly at the top

also. The bottom of a typical ore body is therefore a structural boundary, and the top and sides are commercial boundaries.

The dips of the strata and consequently of the ore bodies average about 20° at Mascot and from 3° to 10° at Jefferson City.

Mine developments at Mascot have reached depths of 800 feet (244 meters) and prospecting has proved the productive horizon to a depth of 1,000 feet (305 meters). At these depths no more pronounced variations in metal content, degree of shattering, or mineral association have been noted than are common at less depths.

The heights of the Mascot ore bodies vary from a minimum of about 15 feet (4.5 meters) to 100 feet (30 meters) and more exceptionally, an average being perhaps 50 to 60 feet (15 to 18 meters). The widths are variable, an average of ore bodies with particularly long dimensions being 125 to 150 feet (38 to 46 meters). In most places the lower third of an ore body is

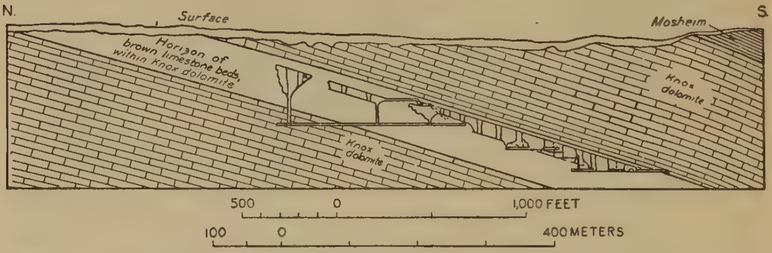


FIGURE 47.—Section showing relation of mine workings to brown limestone horizon, Mascot, Tennessee

of higher grade than the rest. This appears to be explained by the higher grade of the "recrystalline" limestone and the relatively greater shattering commonly present in the lower parts of ore bodies, as the mineralization appears to be somewhat commensurate to the degree of shattering.

*Breccias.*—The breccias in which the ore bodies occur include both rubble breccias and shatter breccias. The most common type of breccia at Mascot is a shatter breccia in which the dolomite has been cracked and seamed but relatively little rubbled. Rubble breccia is formed almost entirely of dolomite fragments ranging in size from small pieces to some as large as a box car and in shape from angular to round. The round fragments were probably formed from the angular by replacement. At Jefferson City the breccia fragments include both dolomite and limestone. Interstices between the fragments of the breccia and cracks in the shattered rock are filled by crystalline white dolomite, locally called gangue dolomite, and sphalerite, which

are partly fillings of openings and partly replacement deposits. Healing of fractures has been practically complete, and vugs are extremely rare.

Though mineralization by sphalerite at Mascot has usually been confined to the beds immediately above the particular "recrystalline" bed that forms the bottom of the ore body, fractures are not generally so confined. Commonly the rock immediately underlying the "recrystalline" bed has been shattered or brecciated also but only slightly mineralized. Apparently when the more brittle dolomite beds were fractured the less resistant limestone readjusted itself by recrystallization possibly to form a stratum relatively impervious to direct circulation. Where associated with shattering, the limestone beds almost invariably to a greater or less degree have taken the "recrystalline" form.

In places both the boulders of the breccia and the matrix are crossed by veinlets of dolomite carrying a little sphalerite. This is considered by some geologists to indicate that the shattering which provided the channels for mineralization was later than the consolidation of the rubble breccia.

Opinion is divided as to the origin of the ore breccias. Those familiar with the mine workings consider that they are due to movement, probably in connection with the regional mountain-making forces. Faults that would account for differential breaking have not been identified in the mine workings at Mascot, though they are a prominent structural feature of the Davis mine, at Jefferson City.

The persistence with which the ore breccias cling to the one general horizon presents a perplexing question. Possibly a differential resistance between the dolomites and limestones of that horizon may be a sufficient explanation, and the breaking may have occurred early in the period of the regional deformation, before folding had advanced far. The unmineralized crushed type of breccia found in areas of close folding described below may have been developed late in the period.

*Folds.*—Folds in or closely adjacent to mine workings are gentle both at Mascot and at Jefferson City. During the early prospecting period at Mascot it was thought that folds at the surface might reflect the presence of ore breccias below. This relation now seems less certain. Prospecting in certain areas with more than the average degree of surface folding has disclosed the presence of crush breccias made up of rather finely divided and evenly sized material, whose fragments are less thoroughly consolidated than those of the ore breccias, and which lack the gangue dolomite typical of the ore breccias. They may represent postmineral folding and crushing.

*Faults.*—Though faults have been recognized in the vicinity of Mascot, no faults of any considerable magnitude have been identified within the mines. Displacements measured by inches, with the downthrust side to the north, are not uncommon beneath the ore bodies. On the other hand, faults are prominent structural features of the Davis mine, at Jefferson City.

*The ore.*—The deposits are remarkable for their simple mineral content. Pyrite and marcasite occur sparingly. Most of the sphalerite is very light yellow. The quantity is variable but is generally greater in the more intensely brecciated rock.

The gangue consists principally of dolomite, which occurs in three different forms—original dolomite country rock, "recrystalline" dolomite, and coarse white gangue dolomite.

The country rock dolomite is the original dolomite of the rubble or shatter breccias. Associated with it in places is some early white chert.

The "recrystalline" dolomite, an alteration product of limestone, is a coarse-grained rock with marblelike texture. It contains varying amounts of chert, which was apparently introduced by progressive replacement subsequent to the development of the dolomite crystals by starting as thin filaments between those crystals. Sphalerite appears as blotches and as disseminated crystals with outlines suggesting replacement of dolomite crystals. It is more abundant in the upper part of a "recrystalline" bed where the bed is the footwall of an ore body.

The gangue dolomite is coarsely crystalline and white. With or without sphalerite it fills the spaces between breccia fragments or occurs in seams in the shattered rock. Etching of sphalerite develops structural lines suggestive of dolomite cleavage. Fragments of country rock in the breccias have rounded edges suggesting replacement. It is likely that sphalerite has replaced both gangue dolomite and breccia fragments. Blue or brown chert is sparsely associated with the gangue dolomite in places. A curious and unexplained habit of sphalerite associated with gangue dolomite in other than vertical seams is its almost invariable occurrence on the lower side with the dolomite on the upper side of the seam.

*Origin.*—No really comprehensive study of the origin of the ores has been made at the mines of this valley. Purdue, Watson, and Secrist, in their surveys of the general district, are inclined to view the sediments as the probable immediate source of the zinc. The absence of known igneous rocks within or near the mine areas and the rather simple mineral make-up of the ores are considered by them to support this view. They regard the mineralizing waters as having been of meteoric origin.

The lack of any general change in metal content or in mineral association with depth in the Mascot mines points to ascending rather than to descending waters. The amount of foreign mineral introduced, in the way of ore, gangue, and replacement material, has been large, indicating a circulation enormous as to volume and probably widespread as to area. Under such conditions the lateral component might very well have been as important locally as the vertical.

Without doubt the brecciated and shattered areas acted as main channels for circulation. If precipitating agents, aside from those that may have been supplied by a mingling of solutions from many sources, were necessary for the localization of the ores within the breccias, the brown limestones, always present in these mines at the horizon of the ore and their breccias, carry organic matter in ample quantity.

The same genetic problems are involved here as in the lead and zinc deposits of the Mississippi Valley. There is the alternative possibility that the mineralizing waters and their metallic content were derived from magmatic sources. Geologists who hold this opinion are inclined to see a regional zonal arrangement between the lead and zinc deposits of the valley of eastern Tennessee and southwestern Virginia and the copper and other metalliferous deposits of the Blue Ridge and Piedmont provinces, to the southeast.